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STATE OF CALIFORNIA
TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

SURVEY OF EARTH-BORNE VIBRATIONS AND THEIR PROBABLE EFFECTS ON PARAMOUNT — DESILU STUDIOS

September 1967

State of California
Highway Transportation Agency
Department of Public Works
Division of Highways
Materials and Research Department

September 1967

Project W. O. 36411

Mr. A. C. Birnie
Deputy District Engineer
District 07
Division of Highways
Los Angeles, California

Dear Sir:

Submitted for your consideration is a report entitled:

A SURVEY OF EARTH-BORNE VIBRATIONS

AND THEIR PROBABLE EFFECTS ON

PARAMOUNT-DESILU STUDIOS

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Principal Investigator

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Co-Investigators

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

JEB/WC:mw

I. INTRODUCTION

Paramount Pictures Corporation, 5451 Marathon Street, Hollywood, California, has expressed their concern that earth-borne construction vibrations, freeway traffic vibrations, and traffic noise from the proposed construction and alignment of the Beverly Hills Freeway would adversely affect their studio operations. The outer edge of the proposed freeway, 07-LA-2, 2.3/11.5, will pass within 350 feet of their studios. Desilu West, Desilu East Studio 14, and Paramount Studios shown in Figure 4 are collectively called Paramount-Desilu Studios.

This is Part 2 of a two part report of which Part 1 is on sound effects and Part 2 on vibration effects.

This survey was initiated by A. C. Birnie, District 07 Deputy District Engineer, by letter dated May 1, 1967, to the attention of Mr. J. L. Beaton, Materials and Research Engineer.

II. CONCLUSIONS

1. During construction of the proposed Beverly Hills Freeway, Paramount-Desilu Studios will not be affected by earth-borne vibrations emanating from the construction of either an elevated viaduct or an elevated fill freeway.

2. After the proposed freeway is completed, Paramount-Desilu Studios will not be affected by earth-borne traffic vibrations emanating from either an elevated viaduct or an elevated fill freeway.

3. Emanation of construction vibrations, beyond a 200 foot boundary of the studios, during the realignment of the city streets (Gower Street, Melrose Avenue, and "XYZ" Street) will not add to or raise the present level of vibrations inside of Paramount-Desilu Studios.

4. After the realignment of Gower Street, Melrose Avenue, and "XYZ" Street", the city street vehicle traffic on them will not add to or raise the present level of vibrations inside of Paramount-Desilu Studios.

III. TEST PROCEDURE

The test procedure consisted of recording earth-borne vibrations emanating from truck traffic at two freeway fills and a structure, from the local street traffic on Melrose Avenue next to Desilu East Studio 14 and from Paramount-Desilu's in-plant operations.

The passage of a Division of Highways lowboy truck, Figure 1, was used as a controlled test truck to create freeway earth-borne vibrations. The load on the lowboy axles are shown in the figure. Note that axles 2 and 3 were loaded to 24,380 pounds and axles 4 and 5 were loaded to 35,160 pounds of the legal load limit of 36,000 pounds. In addition, passages of trucks on the outside freeway lanes were also monitored for earth-borne vibrations at the freeway survey sites.

Freeway vibration measurements during a test run were recorded simultaneously with two seismometers and its associated equipment shown in Figure 2. The seismometers were placed on the ground on a line normal to the pavement edge and at appropriate distances from each other in order to measure the vibration drop-off with distance. Each time the Division of Highways lowboy or a large truck passed by it, the vibration equipment was turned on to record any vertical earth-borne vibrations emanating from the truck passage.

Local street traffic vibrations, Figure 3, from Melrose Avenue next to Desilu East Studio 14 were measured with the two seismometers placed near the curb. Vibration drop-off with distance was not of interest here because the studio butts up to the sidewalk.

Paramount-Desilu in-plant vibrations were measured with the two seismometers placed at various locations of interest.

IV. DISCUSSION

The proposed Beverly Hills Freeway alignment in the vicinity of Paramount-Desilu Studios is shown in Figure 4. The two studio propers are about 1700 feet apart. The closest distance between the outside pavement edge of the proposed freeway and either studio proper is 350 feet.

How much earth-borne traffic vibrations will Paramount-Desilu Studios "feel" if the Beverly Hills Freeway were to be located 350 feet away from their studios? To answer this question, and since the Beverly Hills Freeway is not yet in existence, three existing freeway locations were chosen to simulate the proposed freeway for this vibration survey. These three locations are similar in geological formation, physical structure, and grade to the proposed Beverly Hills Freeway. The three locations are at the San Diego Freeway and Pomona Freeway and are shown in Figures 5 and 6.

The Beverly Hills Freeway could be constructed either as an elevated fill or elevated viaduct freeway. At the San Diego Freeway test site, Figure 5, earth-borne vibrations recorded at Locations A and B were adjacent to the Prairie Street undercrossing. This represented vibrations that could emanate from the proposed Beverly Hills Freeway if designed as an elevated viaduct. Figure 7 is an over-all photographic view of this test site. Vibration records of truck passages were recorded at these two locations. Figure 5 shows that Location A is 3 feet from the structure and Location B is 206 feet away. The largest magnitude of earth-borne vibrations at this location was created by the passage of a tanker and trailer in Run 10. The record of this run is shown in Figure 8 which is a recording of the vertical earth vibrations at Locations A and B due to the tanker-trailer passage. The vibration is measured in inches of peak-to-peak displacement, henceforth called inches for simplicity. At Location A the displacement was 0.00044 inches and the vibration had diminished to 0.00006 inches at Location B. For the passage of the Division of Highways lowboy with its known load at this same location (Figure 9) the displacement was 0.00036 inches at Location A and had diminished to 0.00006 inches at Location B. The lowboy speed was 45 mph. The frequency of these earth-borne vibrations range between 3 - 5 cps and have a duration of 1 - 2 seconds.

A total of 26 truck passage runs was made at Location A and Location B. However, throughout this report only the largest vibrations are cited for each test location.

In terms that are readily understandable, how large or small is a 0.00006 inches of displacement at a point 206 feet away from a freeway viaduct? Consider a piece of newspaper which is in the order of 0.003 inches thick. The ratio between it and 0.00006 inches is 50. In other words, a vibration of 0.00006 inches peak-to-peak is 50 times less than the thickness of a piece of newspaper. Similarly, the earth-borne vibrations beside the undercrossing at Location A, 3 feet away from the freeway viaduct, was approximately 10 times less than a newspaper's thickness.

Vibrations emanating from an elevated earth-fill structure were simulated at Locations D and E, Figure 5, at the San Diego Freeway. A building prevented going out to a further test distance. The Division of Highways lowboy created a vibration of 0.00006 inches at Location D and no recordable vibrations at Location E. Two tankers and trailers, passing by one after another, created vibrations of 0.00008 inches at Location D and 0.00006 inches at Location E. These are the largest vibrations recorded for the above locations in eight truck passages.

In order to confirm the small vibrations measured at the fill portion of the San Diego Freeway, another freeway site was chosen for additional study. This was the Pomona Freeway, Figure 6, in the vicinity of Pomona Boulevard and Via Norte Avenue in the city of Monterey Park. Again the physical characteristics (grade, geological formation, fill) of this site would be similar to the proposed elevated fill Beverly Hills Freeway. Thirty four truck passages were recorded here. The largest vibration, Figure 10, of 0.000060 inches at Location F, was from the passage of a rock hopper and trailer. Note in Figure 6 that vibrations were too small to be measurable at Location G, 150 feet, and Location H, 200 feet from the edge of the pavement. The Division of Highways lowboy's vibrations were immeasurable at these two locations as shown in Figure 11.

This survey also investigated the amount of earth-borne vibrations that would be emanated during the construction of an elevated fill freeway. Vibration measurements were taken at the Colorado Freeway, 07-LA-134, during its construction phase. The measurements simulated vibrations that would emanate from the elevated fill construction of the proposed Beverly Hills Freeway. Caterpillar scrapper-carryall models 621, 631, and 641 with capacity up to 26 yards and up to a gross weight of 100 tons were in use for the fill haul. A record of the vibrations created by the passage of one of these "cats", taken at the corner of Verdugo Road and Chevy Chase Drive, is shown in Figure 12. One of the seismometers, Channel 3, which was only 5 feet away from the moving equipment, shows a vibration of 0.000672 inches. This seismometer was located at the edge of the haul road and visible in the photograph of Figure 13. The other seismometer, located 100 feet away, showed a vibration drop-off to 0.000088 inches.

The above vibrations were the largest out of the eight "cat" scrapper-carryall passages recorded. The distance in which the vibrations would drop off to zero from the "cat" scrapper-carryall passage was not found due to local street traffic creating interference which would mask out the original scrapper-carryall vibrations.

However, the drop-off in a distance of 100 feet was to 0.000088 inches from an original disturbance of 0.000672 inches. It is reasonable to assume that in a distance of 350 feet, the closest that the mainline portion of the proposed freeway will be to Paramount-Desilu Studios, the vibrations will have diminished to a negligible value.

Vibrations emanating from Caterpillar crawler tractors were also measured. Several of these D9 tractors were used to push the scrapper-carryalls in order to aid in loading them. A large amount of noise and vibrations were evident close to the operations. However, at a distance of 140 and 213 feet away, the vibrations were 0.000080 and 0.000060 inches respectively. This is shown in Figure 14.

As a basis for comparison, a vibration survey was conducted inside of a portion of Paramount-Desilu Studios, Figure 17, to determine their present level of in-studio vibrations which would not be attributable to freeway traffic. It is recognized that any studio vibrations would be under their own control and can be rectified by them. The portion surveyed, Figure 17, is also shown and outlined in Figure 4.

The largest in-plant studio vibrations were on the floor of the heating and air-conditioning machinery room. Figure 15 is a photograph of this room showing the seismometer on the floor. Figure 17 shows the heating and air-conditioning room indicated as 101. The vibration inside of this room on the floor was 0.000140 inches. It is to be noted that this was a continuous vibration and not of a transient nature as in freeway vibrations. The vibration on the alleyway (Figure 16) just outside of this room was 0.000200 inches and of a transient nature. The source or nature of this vibration was not determined. Figure 18 is the vibration record for the two locations. A Paramount official had indicated that vibrations from the heating and air-conditioning room have not been a source of problem for them.

Vibration measurements were recorded inside of Power Plant #1. The location is shown on Paramount plan layout, Figure 17, Location 103, and also on Figure 19. Vibrations were small and immeasurable.

A sheet metal shop was located on Paramount's premises as indicated on the layout, Figure 17, Location 105. A Peck, Stoe and Wilcox punch press, Figure 20, was used to shear a 10 gage sheet of steel while a vibration record was made. A seismometer was located within 3 feet of the press. The vibration record is shown in Figure 21. Vibrations on the floor beside the punch press at the instant of metal shearing was 0.000280 inches.

It was of interest to determine the magnitude of city street traffic vibrations transmitted into Paramount-Desilu's studios. A studio official had indicated that occasionally street traffic vibrations would affect the operations of Desilu East

Studio 14. This studio is located at the corner of Melrose Avenue and Gower Street, as shown in Figures 4 and 22. The two seismometers were placed inside of Studio 14 on the floor as shown in Figures 24 and 25. Vibrations were recorded during the passage of heavy vehicles on Melrose Avenue. Six vibration records were made. The scarcity of truck traffic on Melrose Avenue prevented making more records. However, Run #109, a record of a 4 axle semi-truck produced the largest vibration inside of Studio 14. Figure 26 shows this vibration to be 0.000075 inches at the corner of the studio and 0.000060 inches alongside of the interior wall on Melrose Avenue.

A vibration survey was also made outside of Studio 14 on Melrose Avenue. This avenue runs alongside of the studio and carries mainly city street traffic. Both seismometers were placed on the Melrose Avenue sidewalk. One of the seismometers can be seen in Figure 3. Their locations are shown in Figure 22. In general, the street traffic consisted mainly of passenger vehicles and light trucks. The largest vibration was created by a city bus passage. Figure 23 is a record of this passage which was 0.000040 inches.

V. SUMMARY

Figure 27 is a bar graph summary of the maximum vibration levels at each of the test sites. With reference to this figure, Paramount-Desilu Studios will not be affected by construction vibrations during the building of the Beverly Hills Freeway with a separating distance of 350 feet from the freeway outer edge to the nearest studio corners. This is based on measurements of 0.000088 inches emanating from a Caterpillar earthmover at a distance of 100 feet and 0.000060 inches emanating from a series of Caterpillar tractors at a distance of 213 feet. It is reasonable to assume that the above displacement vibrations will have dropped off to a negligible value at a 350 foot distance. In addition, 0.000140 inches of displacement vibrations were measured inside of Paramount's machinery room, a value much larger than from the above construction equipment at the noted distances.

However, vibrations emanating from the realignment construction of the city streets (Gower, Melrose, and "XYZ" Streets) within a 200 foot distance may be felt by the studios. Vibrations measured inside of Desilu East Studio 14 emanating from current local street traffic on Melrose Avenue and Gower Street were equal to the vibrations (0.000060" - 0.000088") emanating from construction equipment at a distance of 200 feet. This level of vibration was barely perceptible by our engineers inside of Studio 14. Therefore, since the studio can tolerate the present level of vibration emanating from Melrose Avenue traffic, vibrations emanating from the construction realignment of the city streets within a distance of 200 feet will not add to or raise the present level of Studio 14's background vibration.

In order to keep in perspective the vibration magnitude being measured, this piece of paper is approximately 0.003 inches thick. The vibration level of 0.000060 inches peak-to-peak created by a series of Caterpillar tractors at a distance of 213 feet is 50 times less than the thickness of this piece of paper.

With reference to Figure 27, Paramount-Desilu Studios will not be affected by earth-borne traffic vibrations emanating from the proposed Beverly Hills Freeway located 350 feet from the studios after the freeway is completed. On the elevated fill portion of the present Pomona Freeway, vibrations from truck traffic had dropped to zero in a distance of 150 feet (see Figure 6). On the elevated fill portion of the present San Diego Freeway vibrations at a distance of 101 feet from the pavement edge were 0.00006 inches (see Figure 5). This was the largest vibration measured at this location distance and was created by several tankers and trailers passing by one after another. Even so, it is reasonable to assume that the vibrations will have dropped to negligible value in 350 feet.

Vibrations emanating from an elevated freeway structure were somewhat larger than from an elevated fill structure. An elevated structure portion of the present San Diego Freeway had a vibration of 0.000060 inches at a distance of 206 feet (see Figure 5). Again it is reasonable to assume that the vibrations will have dropped to a negligible value in 350 feet.

A vibration survey was conducted inside of Paramount-Desilu Studios to determine their present and self-made vibration level. This gave a criterion to compare the studio's vibrations against freeway traffic and construction vibrations. In general, the studio was quite vibration free. Two locations are worthy of comment. On the floor of Paramount's heating and air-conditioning machinery room, the vibration level was 0.000140 inches. This was a continuous steady-state vibration emanating from revolving machinery. A studio official had indicated that vibrations from this machinery room do not affect their operations. The other Paramount-Desilu location worthy of comment is in Desilu East Studio 14. This studio is adjacent to Melrose Avenue. Melrose truck traffic created 0.000060 - 0.000080 inches of vibration inside of this studio.

Comparison of the present background vibration level of Paramount-Desilu Studios indicates it is of a larger magnitude than the vibrations that would emanate from the completed proposed Beverly Hills Freeway or from its construction vibrations.

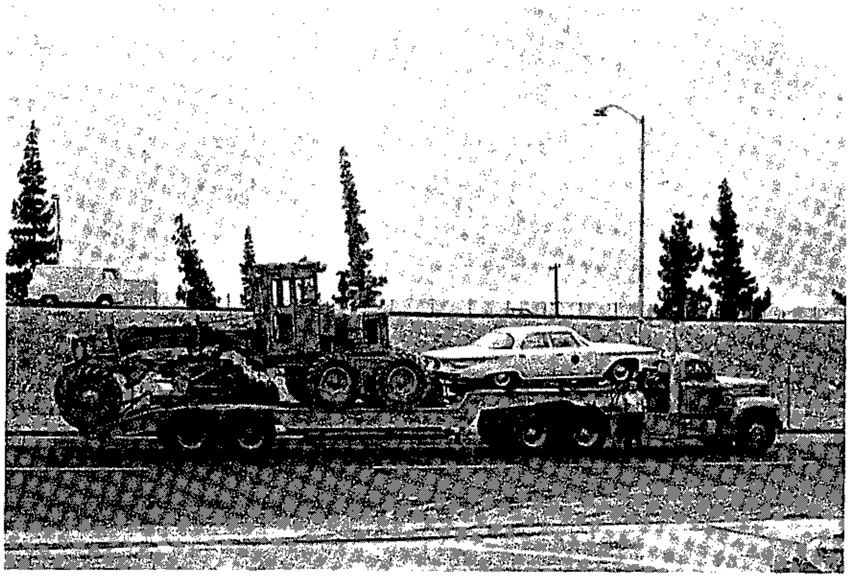
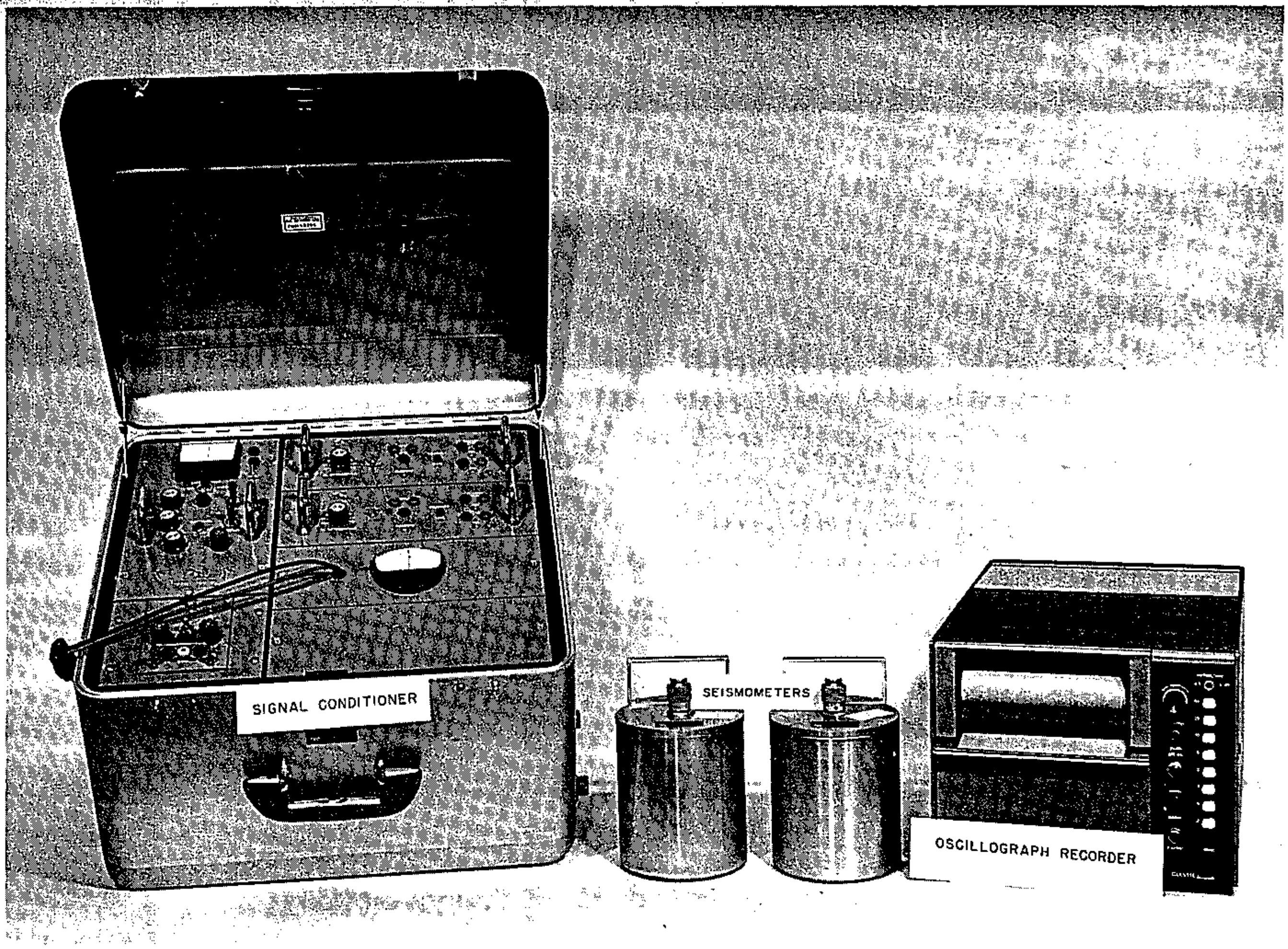


FIGURE 1

Control Test Truck

California Division of Highways Lowboy

Front Axle 1	9,560 pounds
Tractor Axle 2 and 3	24,380 pounds
Trailer Axle 4 and 5	35,160 pounds
Total Weight	69,100 pounds



EARTH-BORNE VIBRATIONS
MEASURING EQUIPMENT

FIGURE 2

FIGURE 3

Melrose Avenue with a Seismometer
in the Foreground

Figure 5

PARAMOUNT - DESILU VIBRATION SURVEY
TEST SITE LOCATIONS

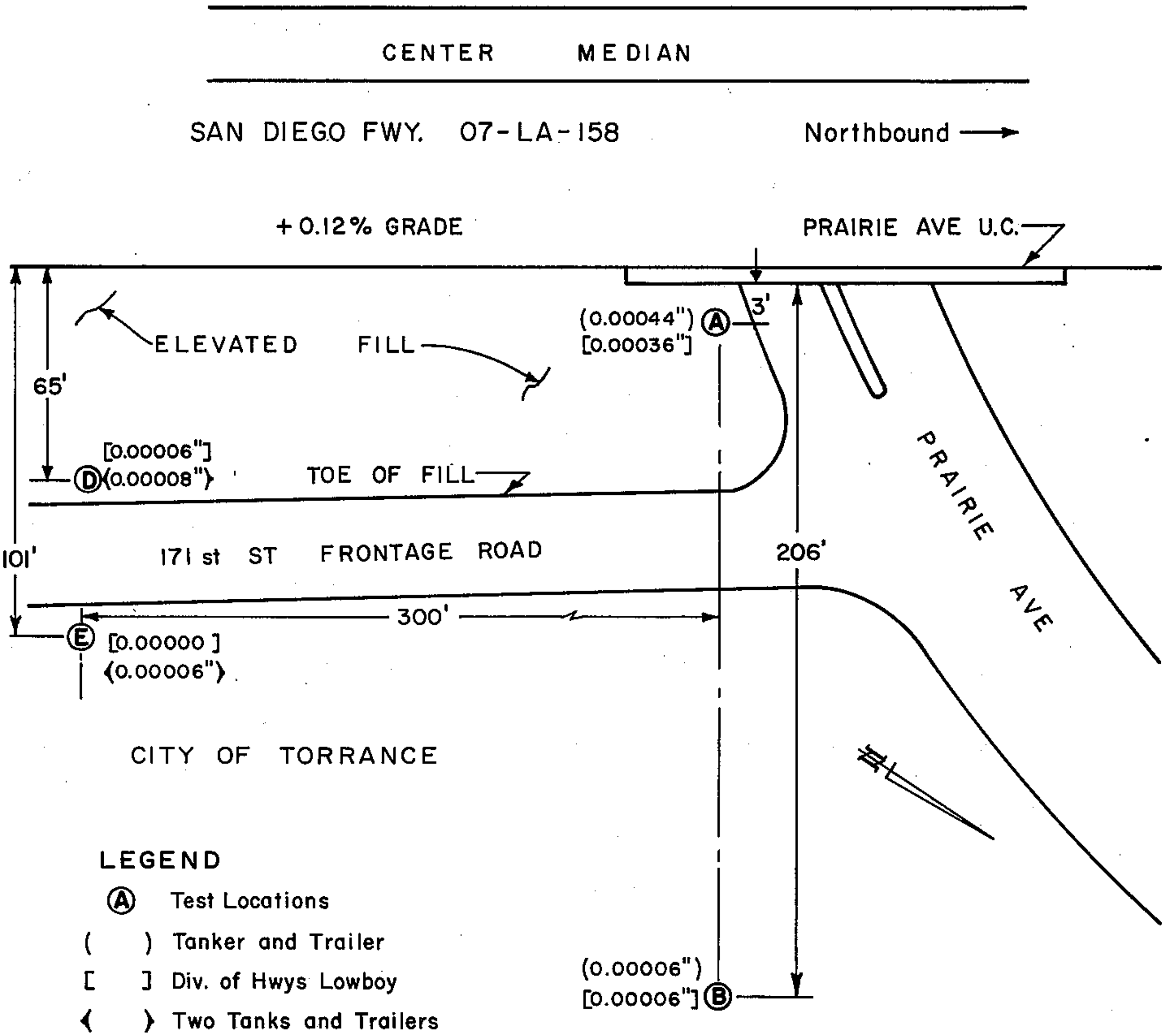
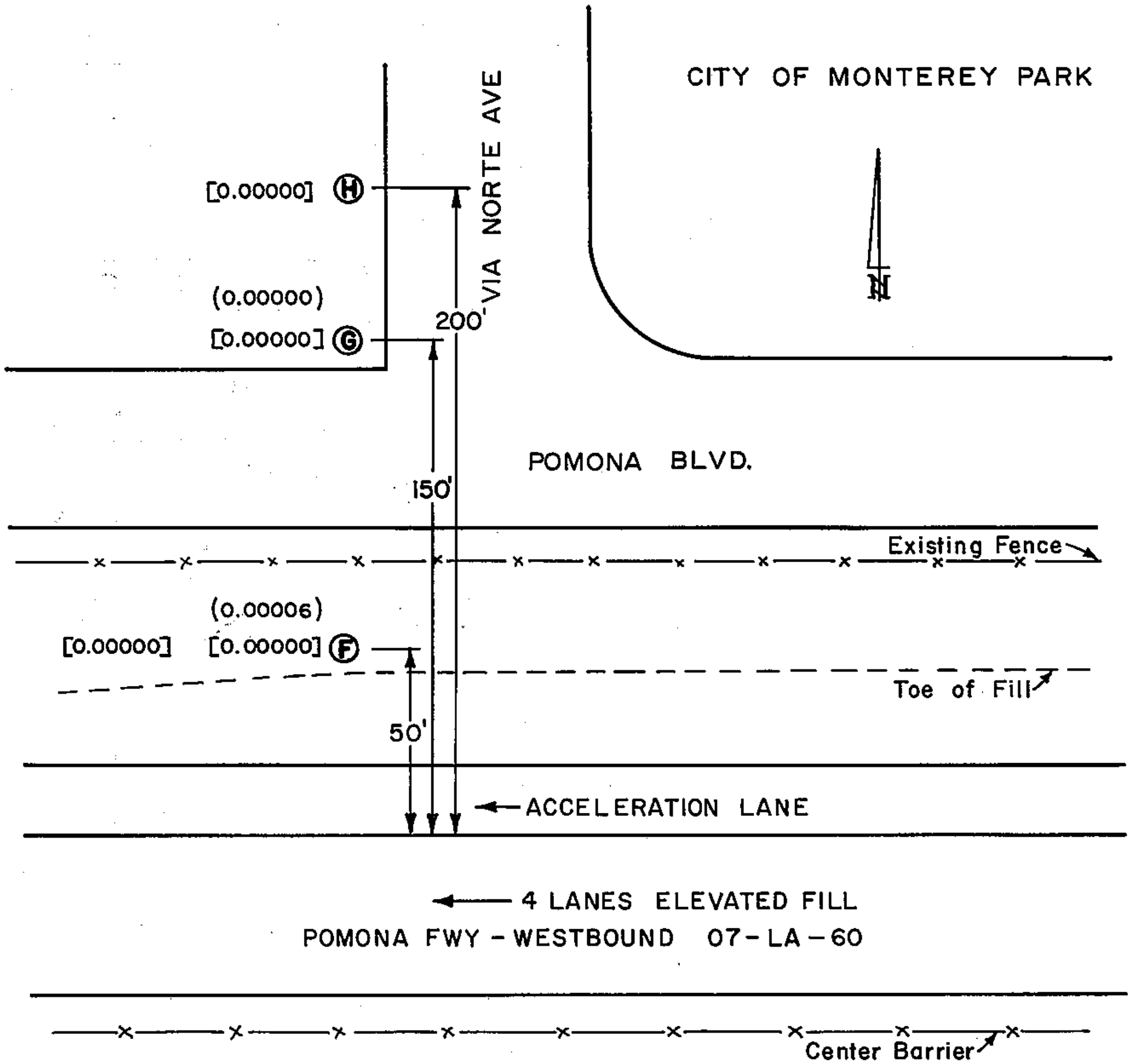


Figure 6

PARAMOUNT - DESILU VIBRATION SURVEY
TEST SITE LOCATIONS



LEGEND

Ⓗ Test Locations

( ) Rock Hopper and Trailer

[ ] Div. of Hwys Lowboy

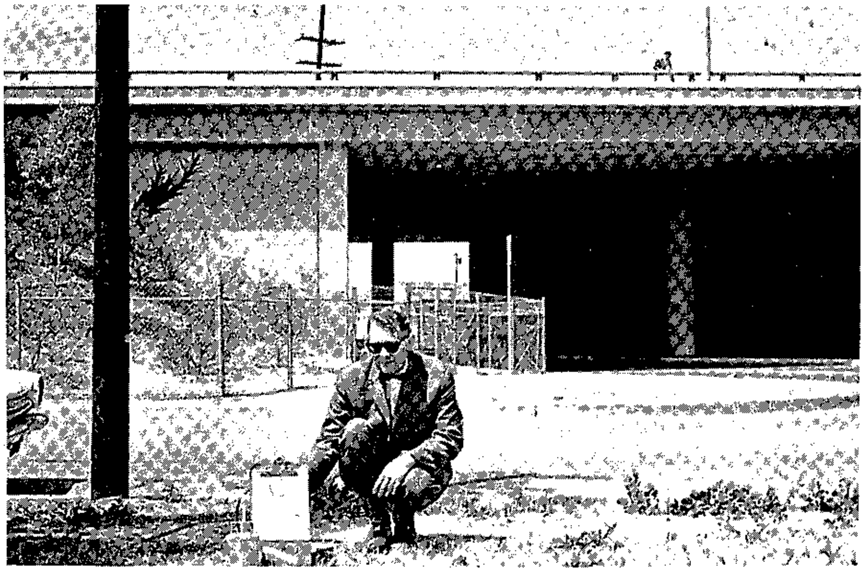


FIGURE 7

Test Locations A, B, and C at the
San Diego Freeway Prairie Street Undercrossing

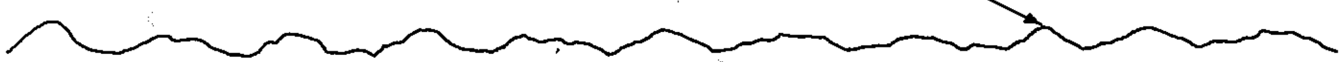
Figure 8

PARAMOUNT - DESILU VIBRATION SURVEY

Vibration Test Record Run No. 10
Date: June 13, 1967
Location: San Diego Fwy, 07-LA-158
City of Torrance, Prairie Street U.C.
Vibration Source: Tanker and Trailer.

Chan 4, Location B

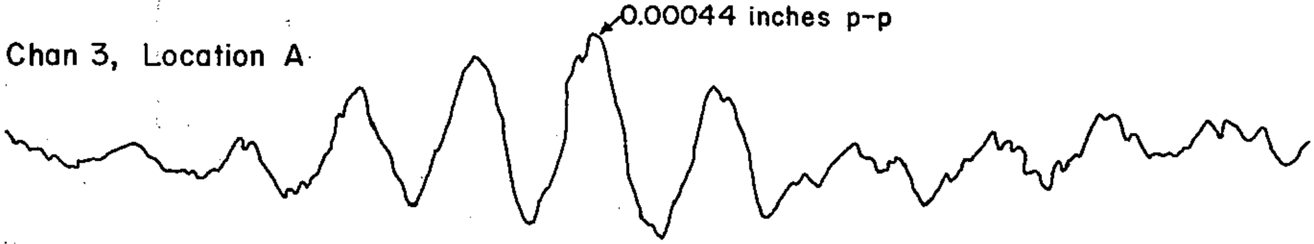
0.00006 inches p-p



206' from Prairie Street U.C.

0.00044 inches p-p

Chan 3, Location A



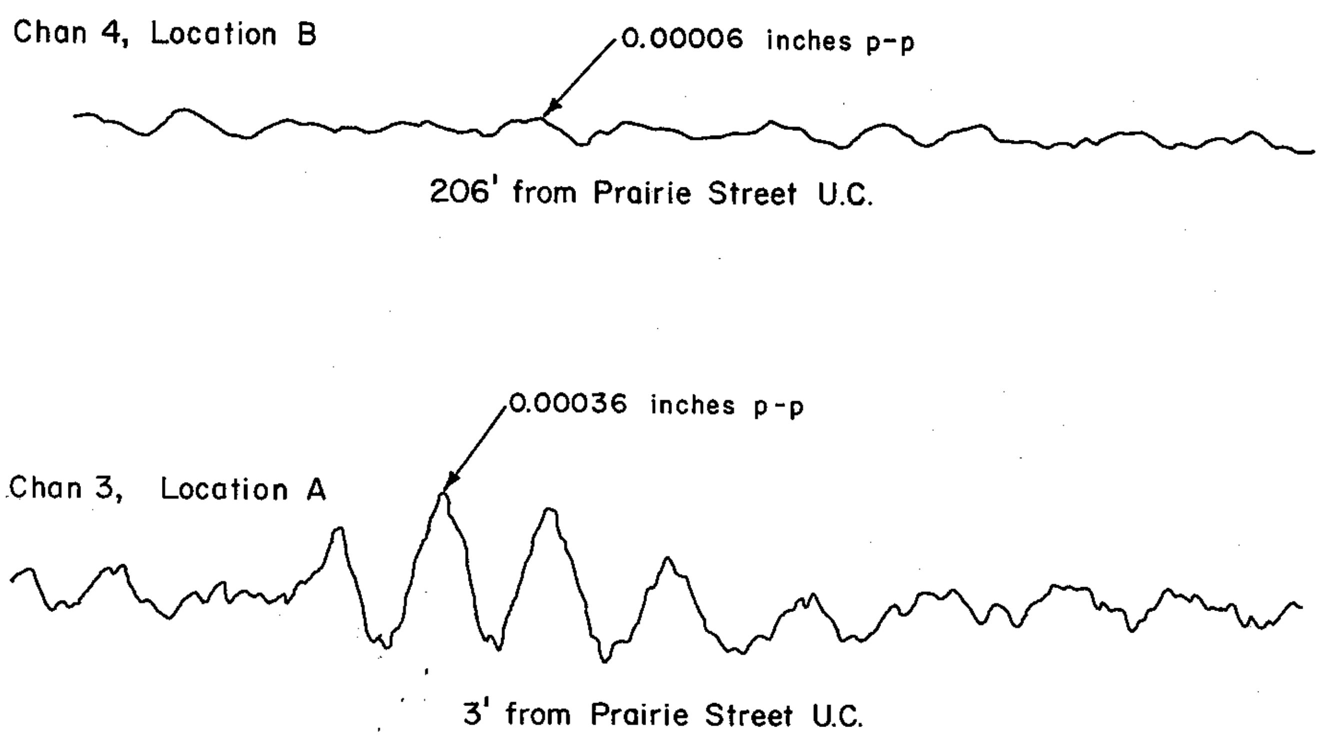
3' from Prairie Street U.C.

→ Truck Travel
Chart speed 2"/sec.

Figure 9

PARAMOUNT - DESILU VIBRATION SURVEY

Vibration Test Record Run No. 26
Date: June 13, 1967
Location: San Diego Fwy. 07-LA-158
City of Torrance, Prairie Street U.C.
Vibration Source: Div. of Hwys. Lowboy Truck at 45 mph.



→ Truck Travel
Chart speed 2"/sec.

Figure 10

PARAMOUNT - DESILU VIBRATION SURVEY

Vibration Test Record Run No. 41
Date: June 14, 1967
Location: Pomona Fwy, 07-LA-60
City of Monterey Park
Vibration Source: Rock Hopper & Trailer at 45-50 mph.

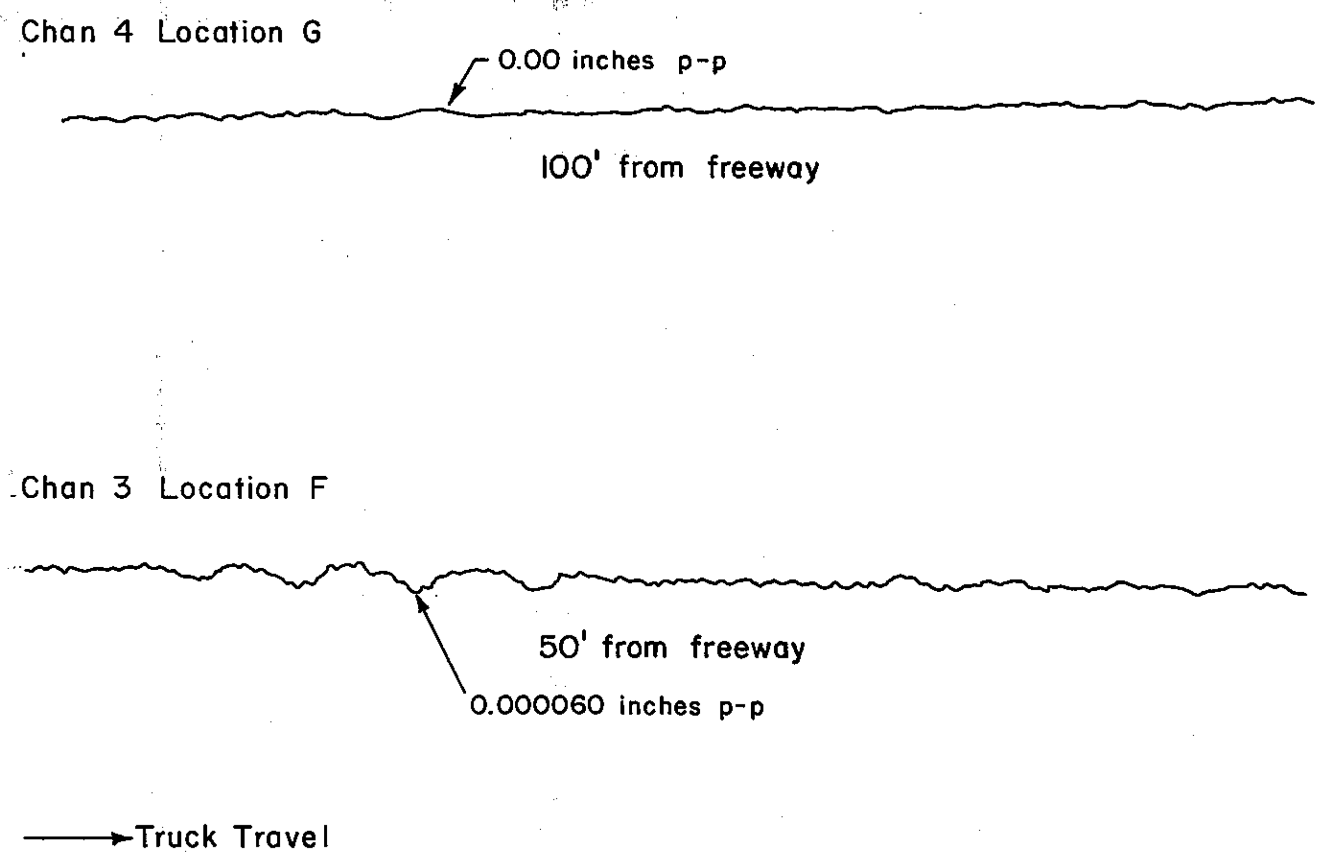


Figure 11

PARAMOUNT – DESILU VIBRATION SURVEY

Vibration Test Record Run No. 59
Date: June 14, 1967
Location: Pomona Fwy, 07-LA-60
City of Monterey Park.
Vibration Source: Div. of Hwys. Lowboy at 55 mph.

Chan 4, Location H

200' from freeway

Chan 3, Location F

50' from freeway

→ Truck Travel

Figure 12

PARAMOUNT - DESILU VIBRATION SURVEY

Vibration Test Record   Run No. 72
Date: June 14, 1967
Location: Colorado Fwy, 07-LA-134,
City of Glendale, Verdugo Street and Chevy Chase Drive.
Vibration Source: Caterpillar Scrapper-Carryall
loaded and traveling full speed.

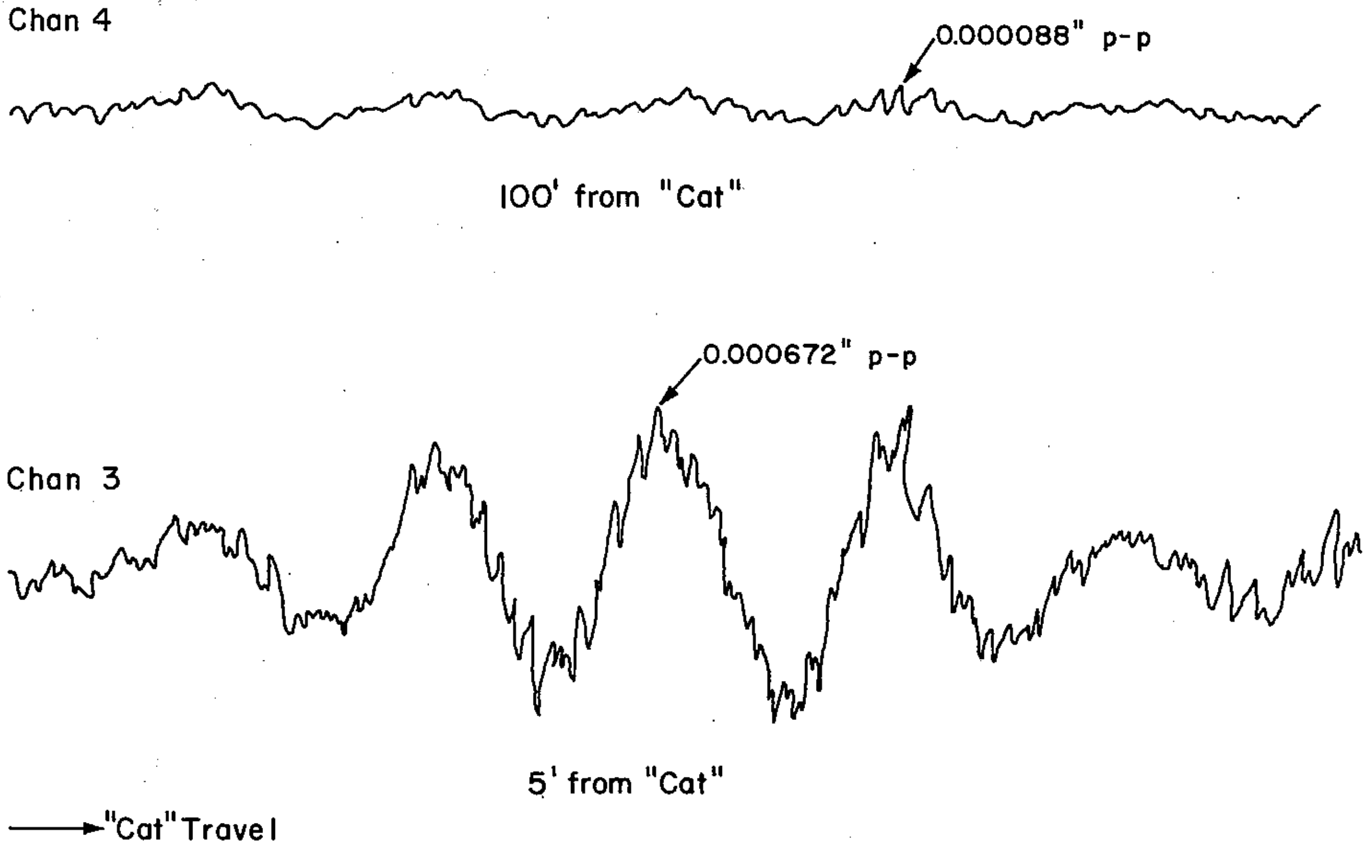


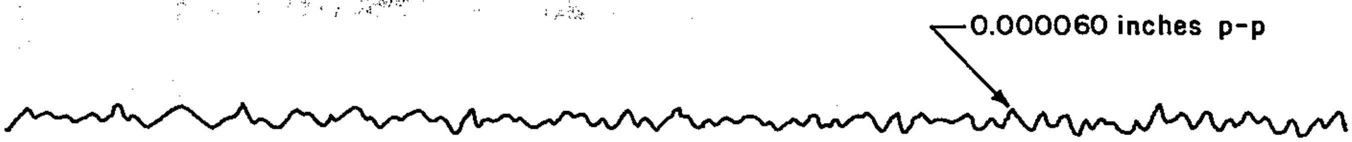
FIGURE 13

Earth-Hauling Equipment

Figure 14

PARAMOUNT - DESILU VIBRATION SURVEY

Vibration Test Record Run No. 88
Date: June 14, 1967
Location: Colorado Fwy, 07-LA-134
City of Glendale
Vibration Source: Caterpillar Crawler Tractors



213 feet from vibration source.

140 feet from vibration source.

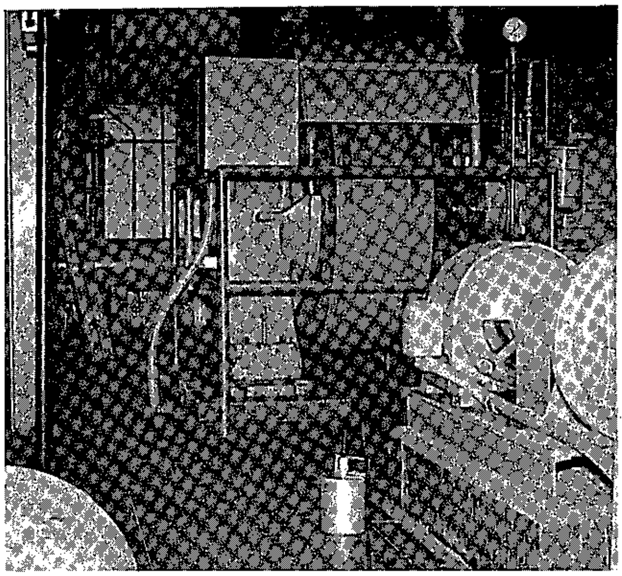


FIGURE 15

View of Seismometer on the Floor of
Paramount's Heating and Air-Conditioning
Machinery Room

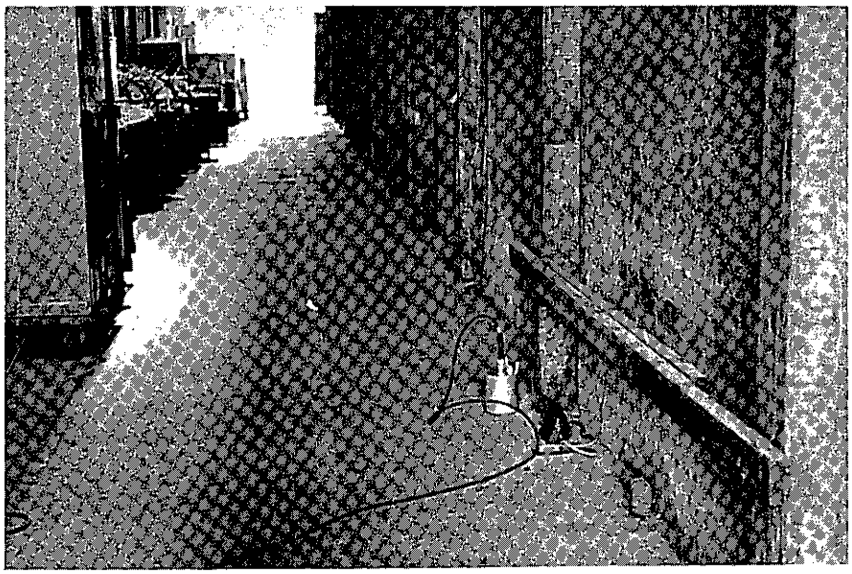


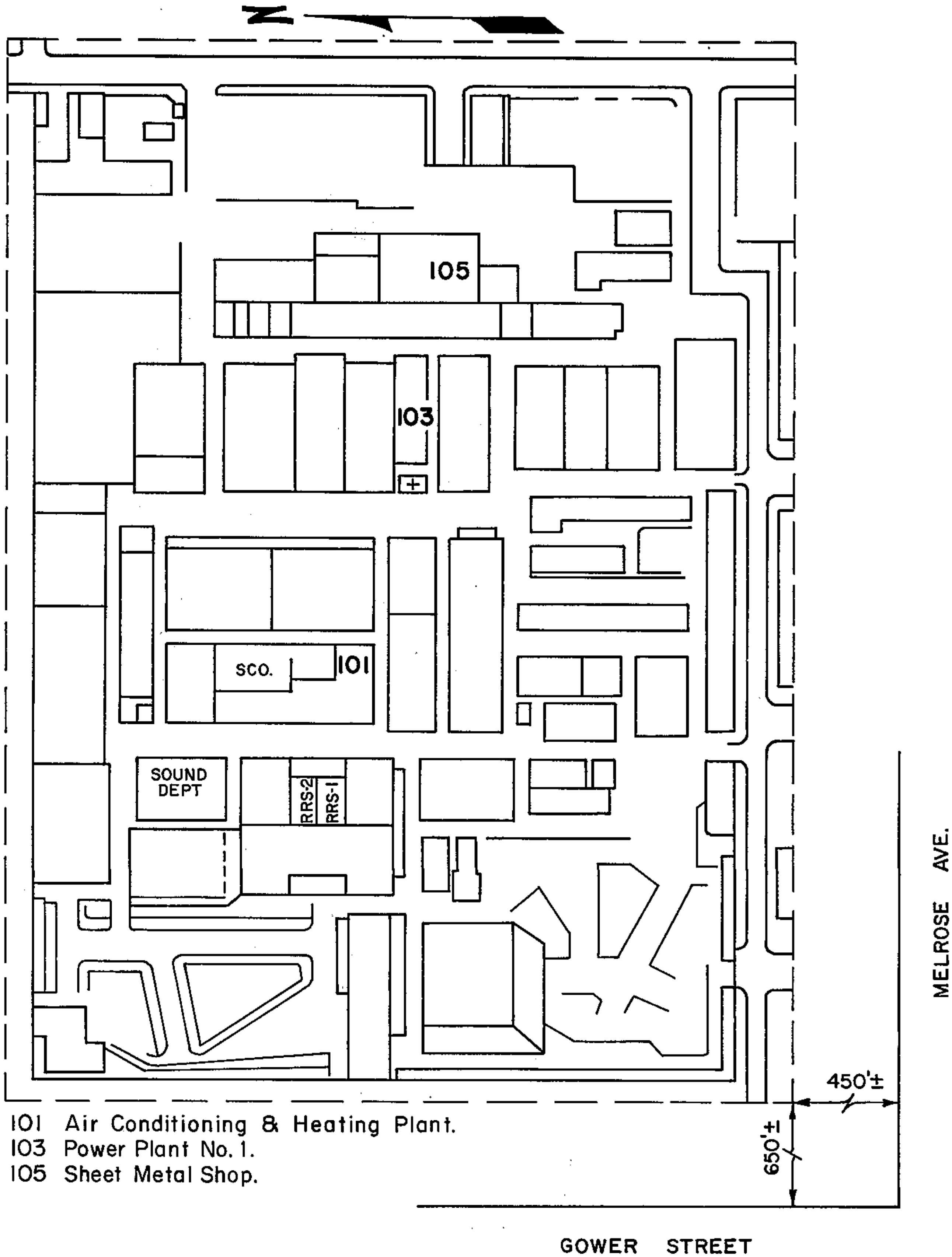
FIGURE 16

Seismometer on Alleyway Outside of the
Heating and Air-Conditioning Room

Figure 17

PARAMOUNT - DESILU VIBRATION SURVEY

IN-STUDIO TEST SITE LOCATIONS



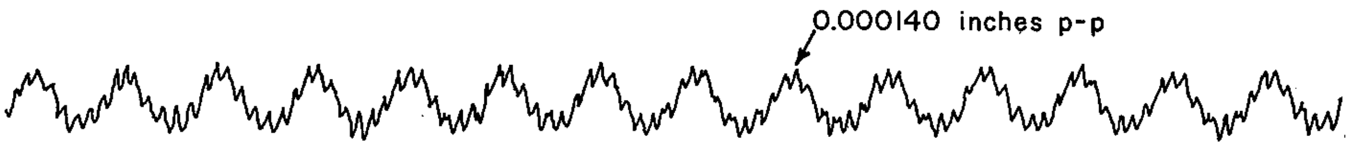
101 Air Conditioning & Heating Plant.
103 Power Plant No. 1.
105 Sheet Metal Shop.

Figure 18

PARAMOUNT - DESILU VIBRATION SURVEY

Vibration Test Record   Run No. 101
Date: June 15, 1967
Location: Paramont's heating and air-conditioning machinery room.
Vibration Source: Machinery in operation.

Alleyway (see fig. 16)



Machinery room (see fig. 15)

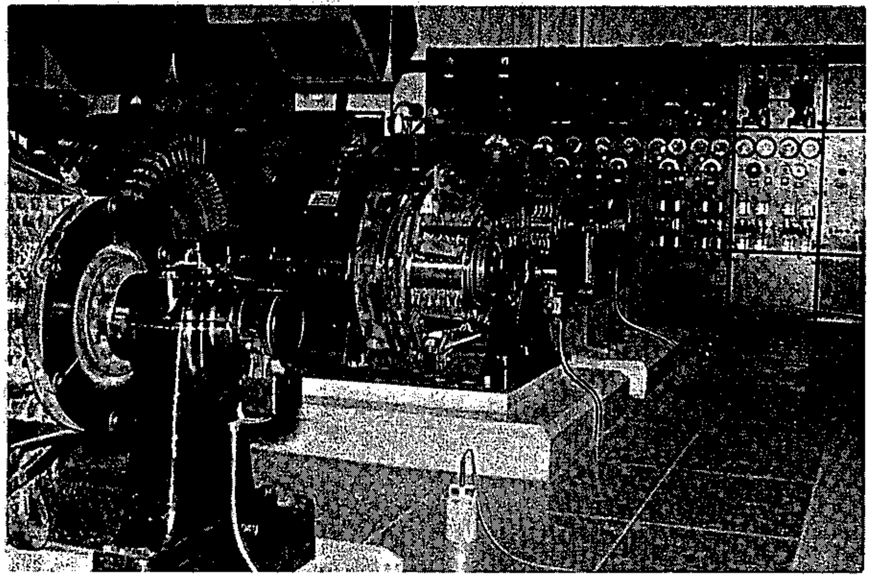


FIGURE 19

Power Plant #1

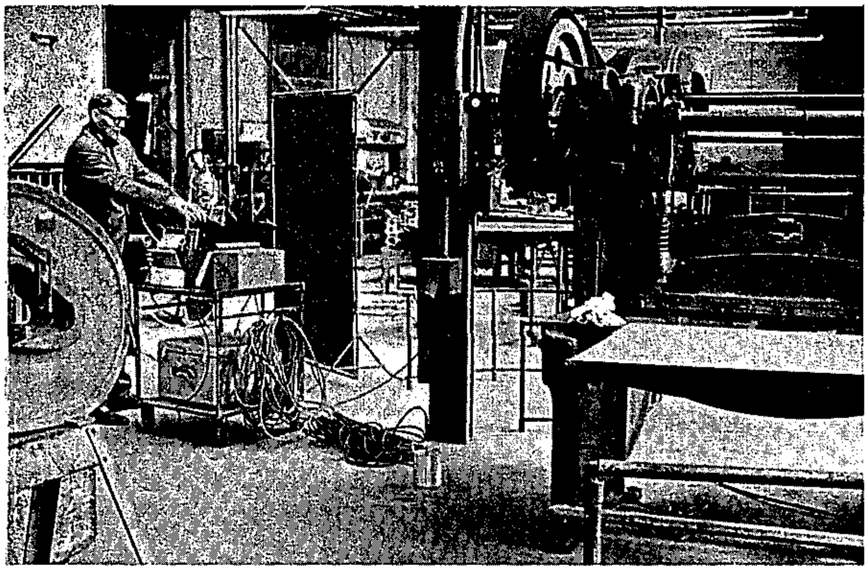


FIGURE 20

Peck, Stow and Wilcox Punch Press

Figure 21

PARAMOUNT - DESILU VIBRATION SURVEY

Vibration Test Record   Run No. 105
Date: June 15, 1967
Location: Paramont's metal shop.

Vibration Source: Peck, Stow & Wilson Punch Press.

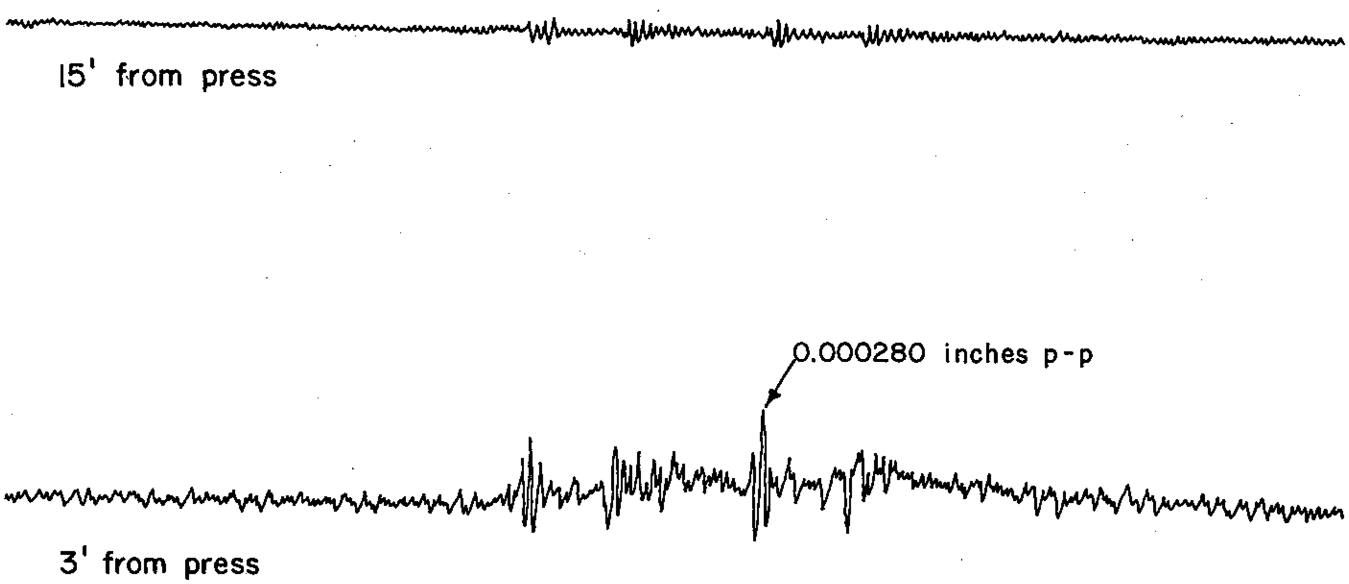
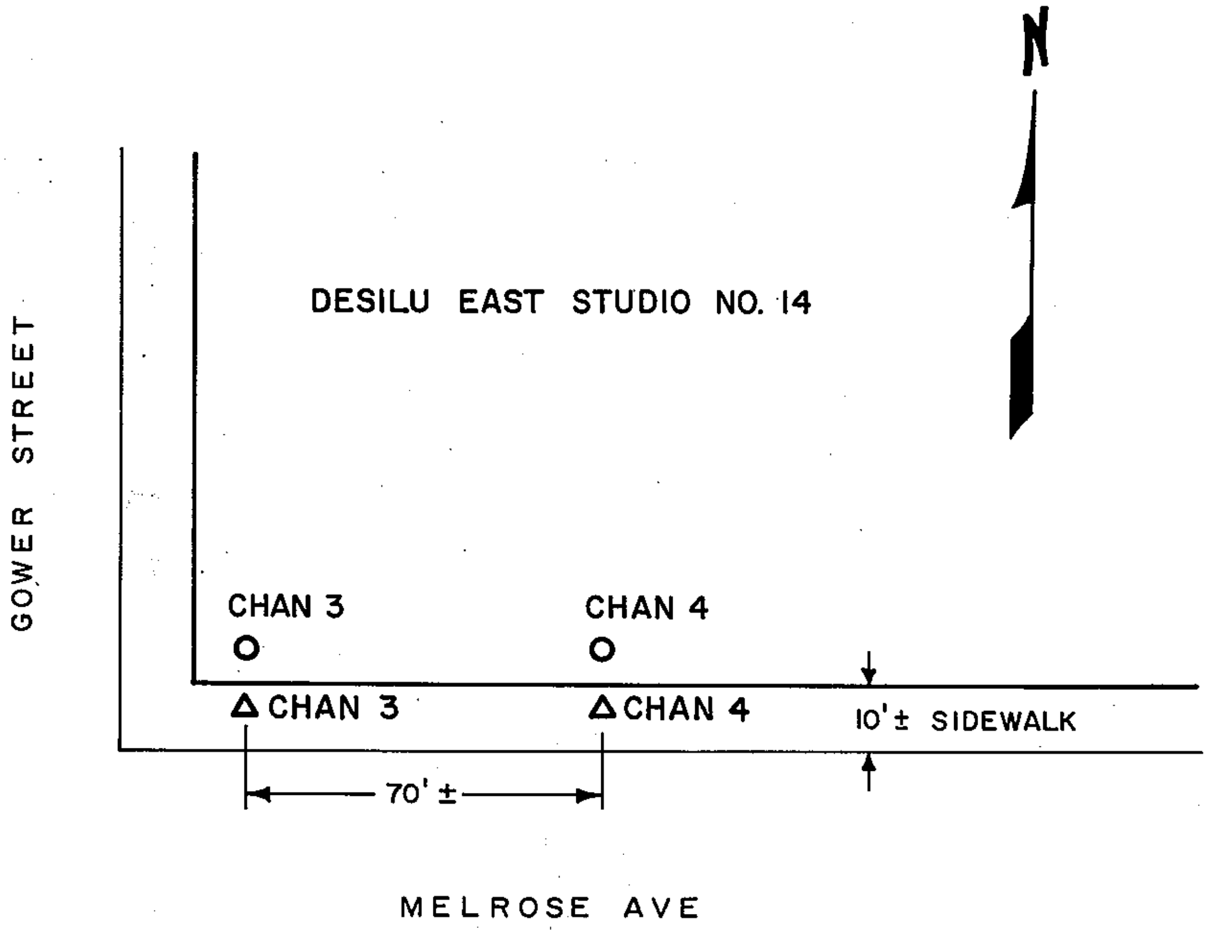


Figure 22

PARAMOUNT-DESILU VIBRATION SURVEY

07-LA-60



SEISMOMETER LOCATIONS

O - Run 109 In studio

Δ - Run 114 On sidewalk

Figure 23

PARAMOUNT – DESILU VIBRATION SURVEY

Vibration Test Record Run No. 114
Date: June 15, 1967
Location: Melrose Avenue at Gower Street, Hollywood.
Vibration Source: City bus passage

On sidewalk (CHAN. 4)

On sidewalk (CHAN. 3)

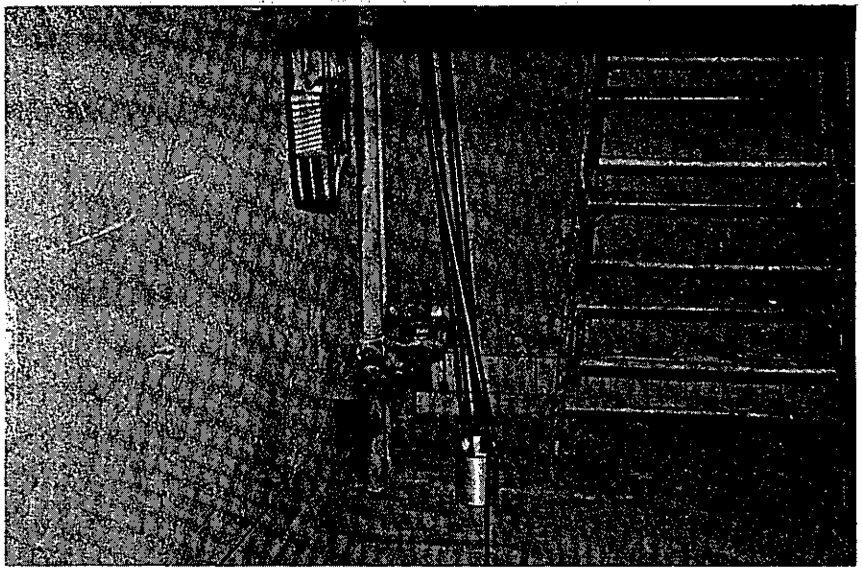


FIGURE 24

Southwest Corner of Desilu East Studio 14

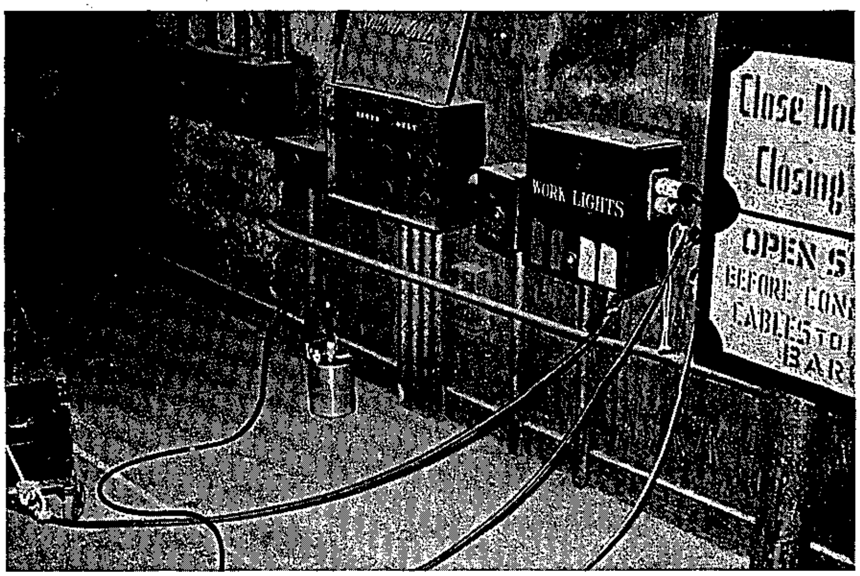


FIGURE 25

Interior Wall of Desilu East Studio 14

Figure 26

PARAMOUNT - DESILU VIBRATION SURVEY

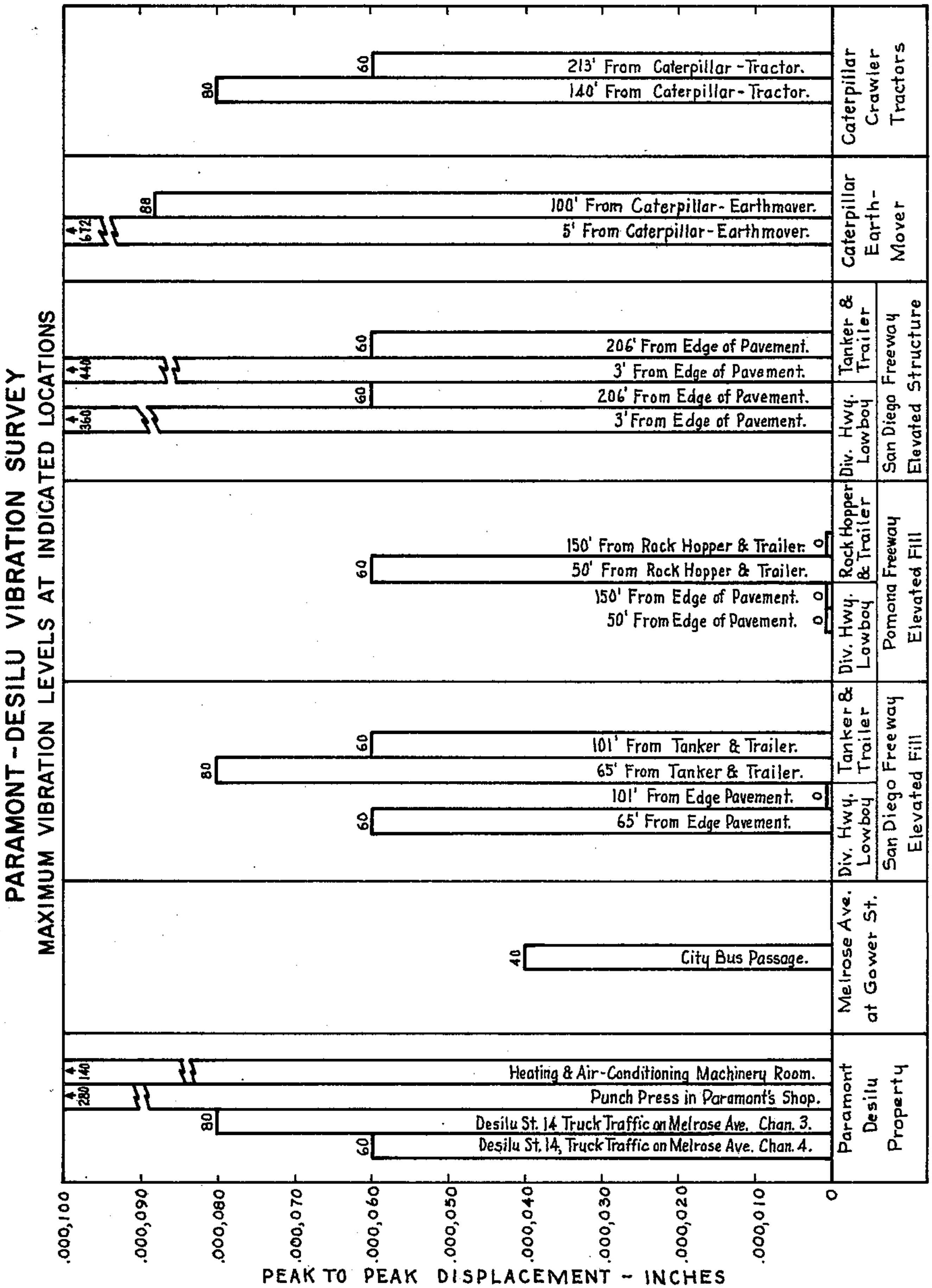
Vibration Test Record Run No. 109
Date: June 15, 1967
Location: Inside of Desilu Studio No. 14

Vibration Source: Truck Traffic on Merose Avenue, Hollywood

Studio interior wall (Fig. 25)

SW Corner of studio (Fig. 24)

Figure 27


PARAMONT - DESILU VIBRATION SURVEY
MAXIMUM VIBRATION LEVELS AT INDICATED LOCATIONS
PEAK TO PEAK DISPLACEMENT - INCHES
.000,100
.000,090
.000,080
.000,070
.000,060
.000,050
.000,040
.000,030
.000,020
.000,010
0
Caterpillar Crawler Tractors
213' From Caterpillar - Tractor.
140' From Caterpillar - Tractor.
Caterpillar Earth-Mover
100' From Caterpillar - Earthmover.
5' From Caterpillar - Earthmover.
Tanker & Trailer
Div. Hwy. Lowboy
San Diego Freeway Elevated Structure
206' From Edge of Pavement.
3' From Edge of Pavement.
206' From Edge of Pavement.
3' From Edge of Pavement.
Rock Hopper & Trailer
Div. Hwy. Lowboy
Pomona Freeway Elevated Fill
150' From Rock Hopper & Trailer.
50' From Rock Hopper & Trailer.
150' From Edge of Pavement.
50' From Edge of Pavement.
Tanker & Trailer
Div. Hwy. Lowboy
San Diego Freeway Elevated Fill
101' From Tanker & Trailer.
65' From Tanker & Trailer.
101' From Edge Pavement.
65' From Edge Pavement.
Melrose Ave. at Gower St.
City Bus Passage.
Paramont Desilu Property
Heating & Air-Conditioning Machinery Room.
Punch Press in Paramont's Shop.
Desilu St. 14 Truck Traffic on Melrose Ave. Chan. 3.
Desilu St. 14, Truck Traffic on Melrose Ave. Chan. 4.
60
80
88
672
440
360
40
140
280
0

FACTORS AFFECTING THE DURABILITY OF CONCRETE BRIDGE DECKS

Phase I: Construction Practices

Interim Report

By

C. F. Stewart, Senior Bridge Engineer
B. F. Neal, Assistant Highway Engineer

California Division of Highways

ABSTRACT

Construction history was recorded ... ete bridge deck ... in concr... and curing ... lty will be ... with cr... resista... ng index, a... crack surveys show con... age to have a significant effect on cracking. Also, the pre-traffic cracking pattern is significantly unlike that found on similar structures after normal traffic usage. Hence, conclusions on the study's objectives are deferred pending a post-traffic survey.

Normal construction problems hampered control of variations and data collection. These problems will most likely reduce the studies' over-all effectiveness.

Not For Publication

STATE OF CALIFORNIA
TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

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in cooperation with the
U. S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

August, 1967

Presented at the Annual Meeting of the Highway Research Board on January 18, 1968, by D. F. Downing

FACTORS AFFECTING THE DURABILITY OF CONCRETE BRIDGE DECKS

Phase I: Construction Practices

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INTRODUCTION

The effect of construction practices on concrete deck durability is the objective of a study on 7 grade separations, constructed by Peter Kiewit Company, on Interstate 210 near Los Angeles. These structures were selected for the construction practices phase of an extensive study of deck durability due to the close proximity of the batching plant and the fact that each deck pour would be approximately the same size and shape. This would provide an opportunity to virtually eliminate the effects of common variables such as mixing time, aggregates, structure configuration, and duration of placement.

Each structure is a single span concrete box girder supported on abutment walls of 4° maximum skew. Thus, negative moment and skew variables are not present. Most significant, however, is that the absence of approach fills kept vehicular traffic off the decks for a considerable time after they were constructed, thus affording an excellent opportunity to separate shrinkage and traffic influence on deck cracking.

The structures vary in length from 60 to 91 feet (Figure 1) and in width from 146 to 170 feet. The excessive width necessitated each deck being placed in 4 separate units. This resulted in 28 placements available for study.

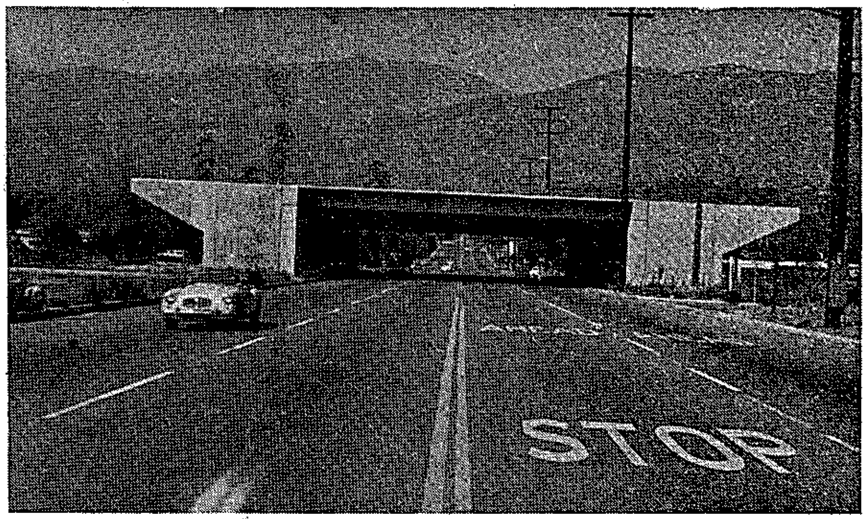


Fig. 1. Typical Structure

VARIABLES

Seven of the placements, one on each structure, were selected as controls to which the others could be compared. Variations were made in one or more of the construction techniques in the remaining 21 placements. These included concrete slump, type of strike-off machine, type and application timing of finishing floats, method of texturing, and method and time of applying the cure. The control and variable techniques are shown in Figure 2.

PLANNED PLACEMENT VARIABLES

MACHINES

a. Bidwell (Control)
b. Borges
c. Trueline
d. Clarey
e. Clarey over-worked

FINISHING

a. Float once, approximately 45 minutes after strike-off, with a wooden 16' longitudinal plow handle float (control)
b. Float once as early as possible with wooden float
c. Float once as late as possible with wooden float
d. Float twice - early and late
e. Float once at standard time with two 6-inch diameter aluminum pipes placed parallel at 1-foot apart

TEXTURING

a. Stiff bristle broom (Control)
b. Burlap drag
c. Wooden finishing float

CURING

a. Fog as needed during finishing followed with wet rugs when set (Control)
b. Delayed placement of wet rugs
c. Monomolecular evaporation retarder placed during strike-off and finishing operations followed with wet rugs when set
d. Membrane curing compound placed after texturing followed with wet rugs the next day.

SLUMP

a. 4-inch (Control)
b. 2½-inch
c. 6-inch
d. Pozzolith 8

Fig. 2

A 4-inch slump was the control with 2½ and 6-inch slumps as variables. (California currently equates one inch of Kelly ball penetration to 2 inches of slump, but plans to change over to penetration limits in the near future.)

The Bidwell (Figure 3) strike-off machine was adopted as a control machine. Others included: Trueline (Figure 4), Borges (Figure 5), and Clarey (Figure 6).

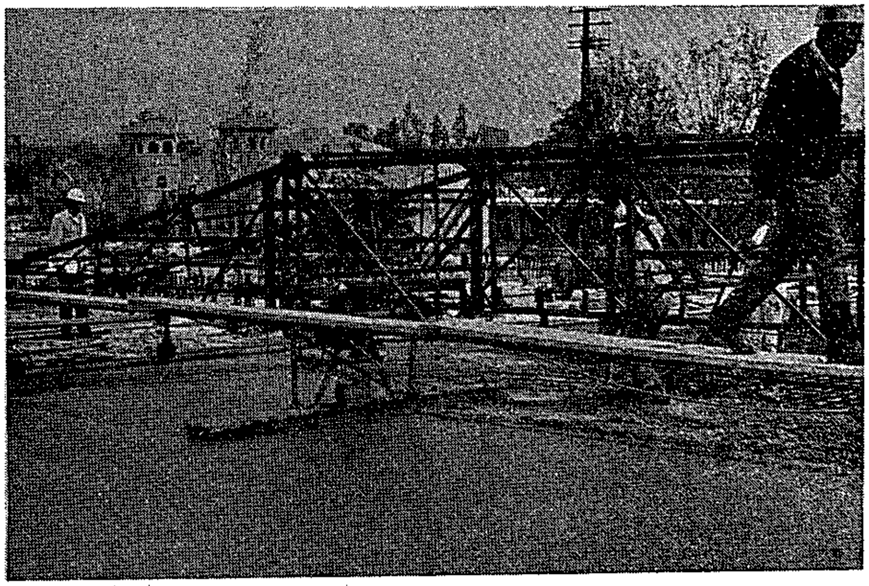


Fig. 3. Bidwell strike-off machine

The control finishing float was a wooden 16 foot longitudinal plow handle float (Figure 7) applied approximately 45 minutes behind the strike-off machine. Variables included one floating as close behind the strike-off machine as possible, one floating as late as the workability of the concrete would

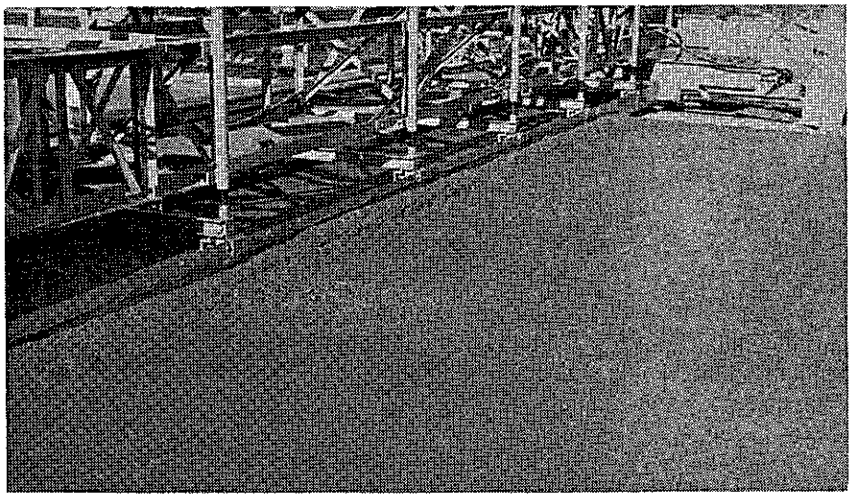


Fig. 4.

Trueline strike-off machine

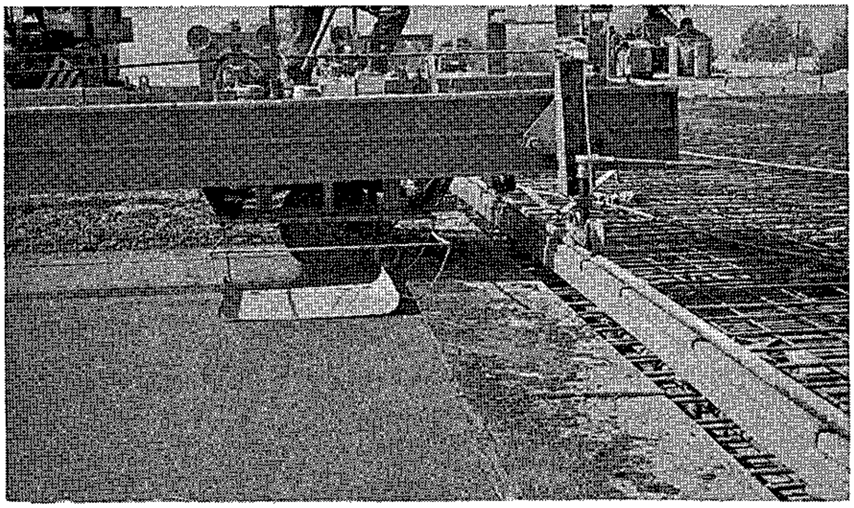


Fig. 5.

Borges strike-off machine

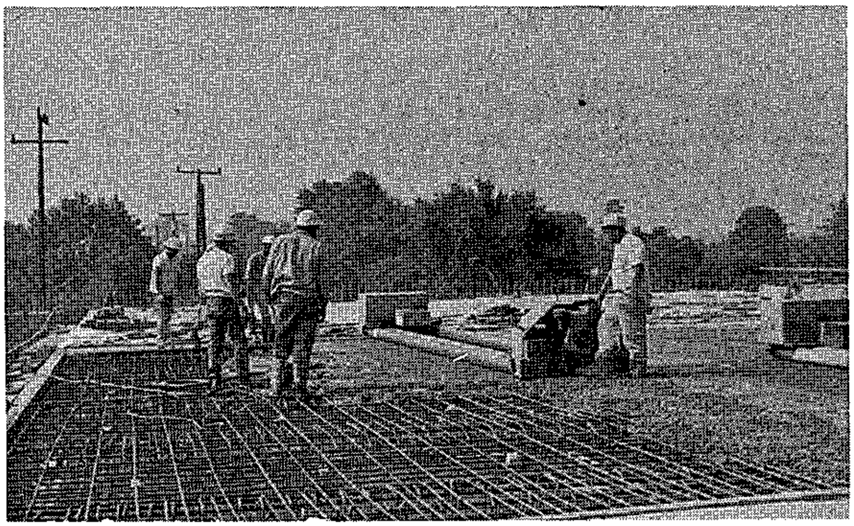


Fig. 6.

Clarey strike-off machine

permit, and a combination of both an early and late floating, all with the wooden float; floating at the standard time with two 6-inch diameter, 10-foot long aluminum pipes in tandem (Figure 8); and floating at the standard time with a single 4-inch diameter 10-foot long aluminum pipe equipped with a handle for full floating control (Figure 9). All floating was transversely applied.

The standard texturing was achieved with a stiff bristle broom (Figure 10). The texturing variables were burlap drag (Figure 11) and natural texturing by the longitudinal wooden float (Figure 12). All texturing was transversely applied.

The standard 7 day cure was provided by wet rugs (Figure 13) with variations of delayed cures and liquid membrane type curing compounds (Figure 14). The membrane cures were supplemented with the wet rugs the day after the cure began. A monomolecular film evaporation retarder was used on four placements prior to the standard cure.

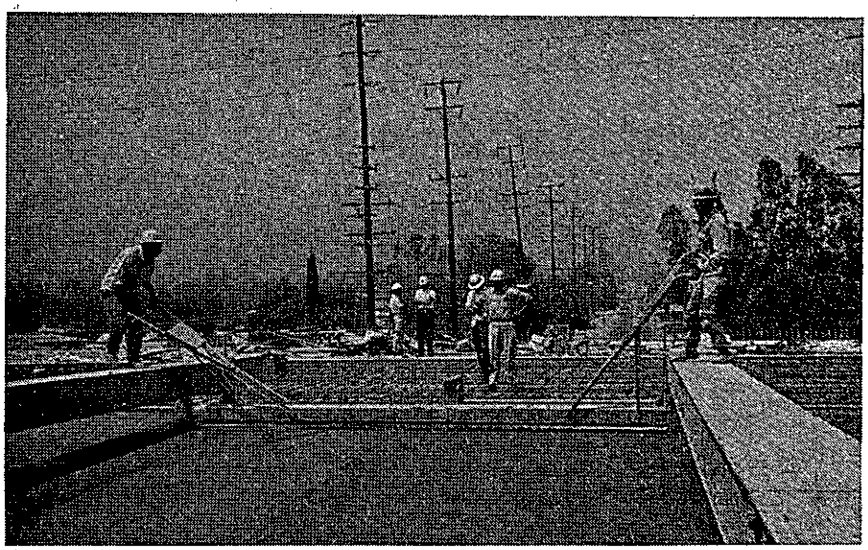


Fig. 7.

16 foot longitudinal plow handle float

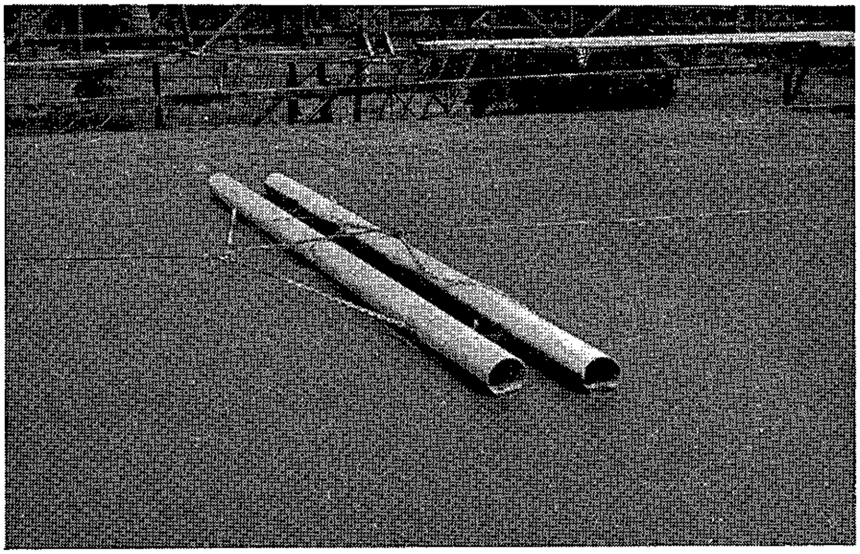


Fig. 8.

6-inch diameter, 10-foot long aluminum pipes float in tandem

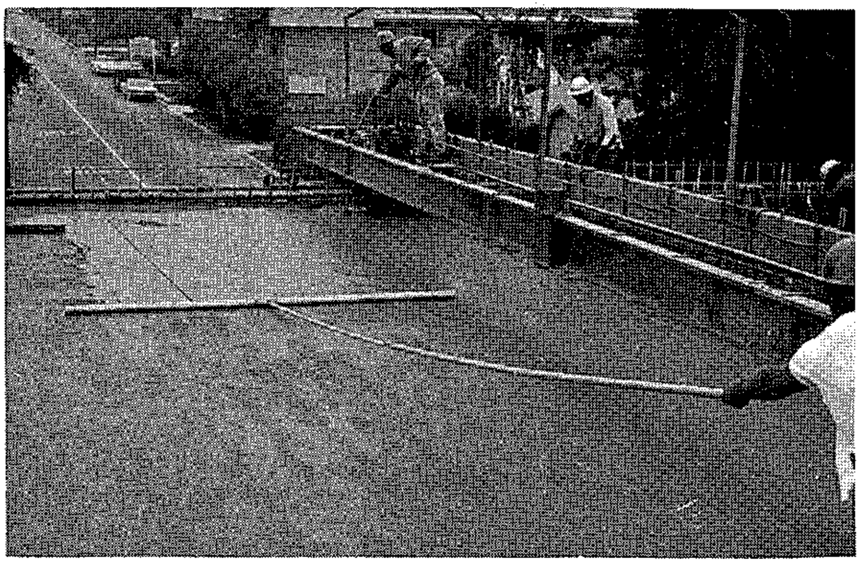


Fig. 9.

4-inch diameter, 10-foot long aluminum float with handle

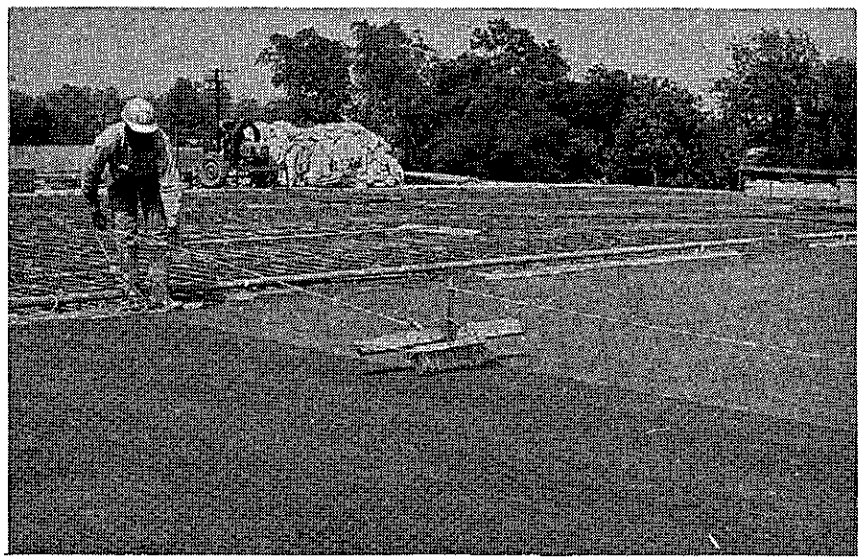


Fig. 10.

Surface texturing with stiff bristle broom

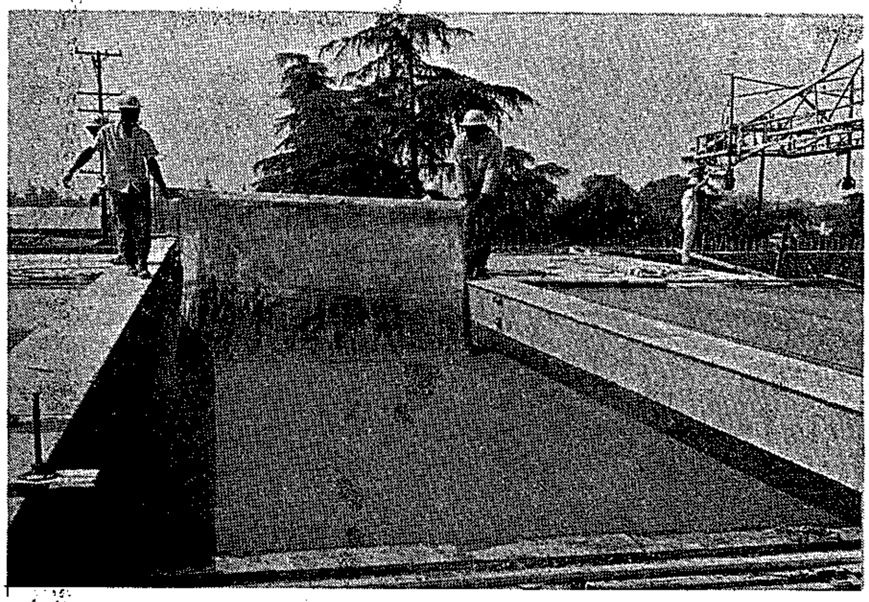


Fig. 11.

Surface texturing with burlap drag

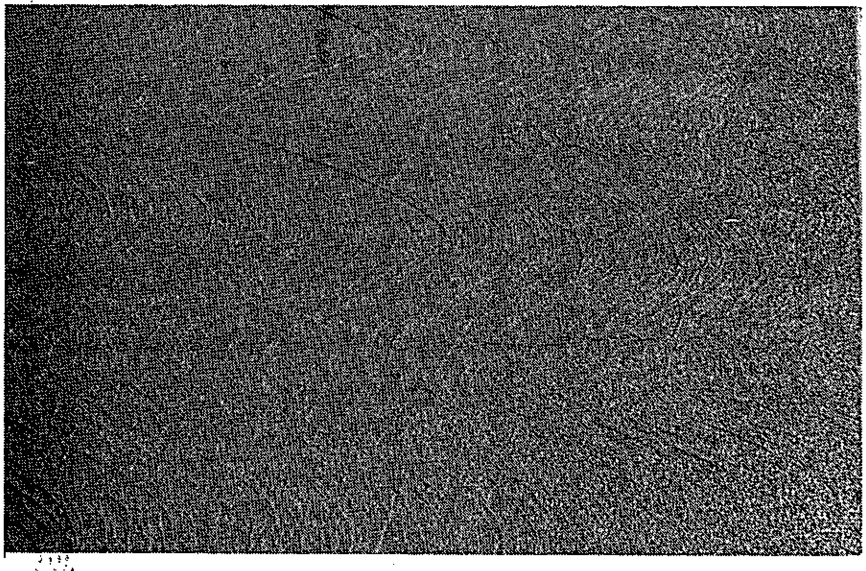


Fig. 12.

Natural texturing by longitudinal wooden float

Fig. 13.

Placing rugs for a wet rug cure

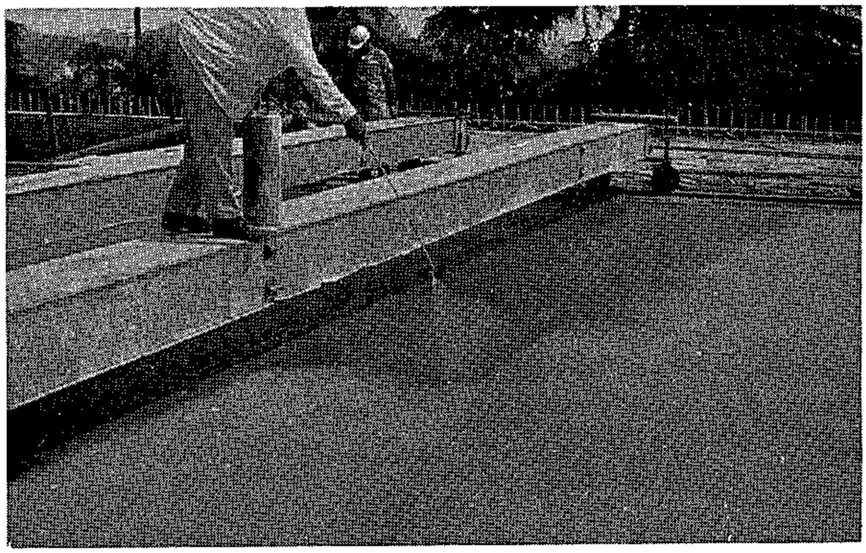


Fig. 14.

Applying liquid membrane type curing compound

DATA COLLECTION

Previous experience has shown that normal construction records do not contain enough detail to correlate final results with placement conditions. The records reflect average construction conditions whereas the final results are most often affected by conditions which vary from the average. To furnish a more complete picture of placement conditions, an unprecedented quantity of data were collected during these placements.

During each placement, a minimum of seven men were engaged in either collecting data or assisting in maintaining construction control. Two men at the batch plant checked the batch proportions, obtained cement and aggregate samples and recorded the quantity of water added to the mix from cleaning operations. One man at the job site controlled the water added to produce the desired slump, recorded slump (Figure 15) and concrete temperature measurements, made unit weight tests (Figure 16), and fabricated test specimens (Figure 17). Two men conducted normal inspection duties, coordinated control of operational timing variables, and placed grid reference points in the finished concrete (Figure 18).

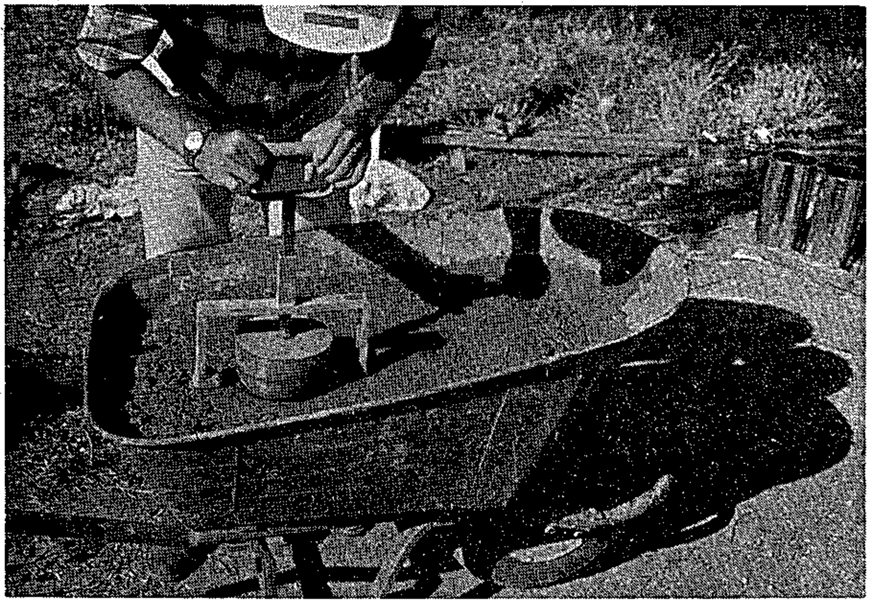


Fig. 15.

Measuring concrete slump with a "Kelly Ball"

Fig. 16.

Making unit weight test

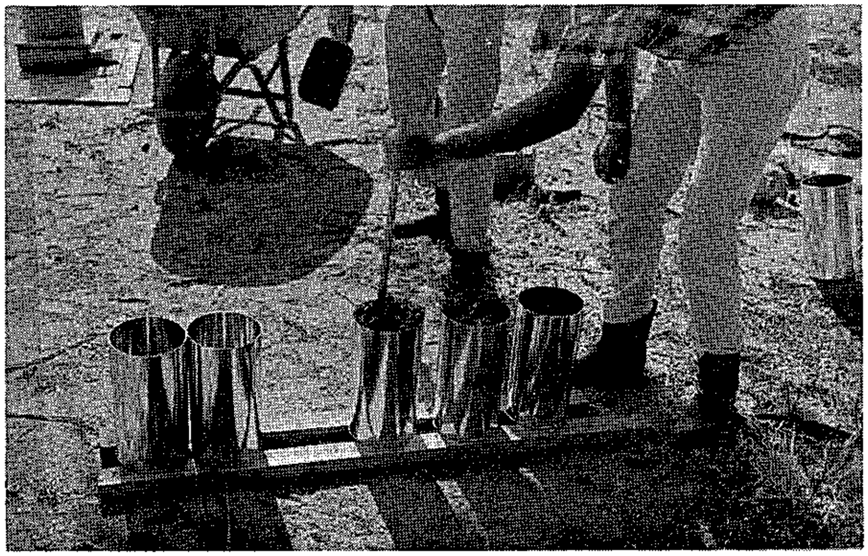


Fig. 17.

Fabricating concrete cylinder test samples

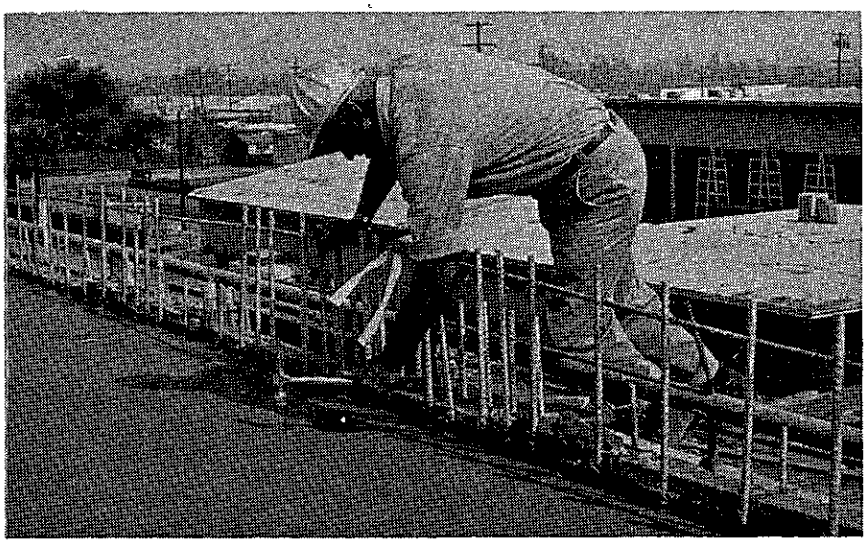


Fig. 18.

Placing grid reference points

A majority of the construction data was collected by a 2-man observation team. A typical packet used by this team to record events during each placement is included as Appendix A. The collected data includes:

1. Condition of forms, support and tying of reinforcing steel, and depth of cover over the steel.

2. The in-place location of each batch of concrete (Figure 19).
3. A time history on each batch of concrete: total batch time, when placed in the deck, vibrated, struck-off, finished, textured, and cured. Also, the number of passes made by the strike-off machine and finish float was recorded.
4. Irregularities such as: over or under vibration, excessive bleed water areas (Figure 20), premature drying areas, areas where excessive walking in the fresh concrete occurred (Figure 21), etc.
5. Weather history of temperature, humidity, wind direction and velocity, and rate of evaporation (Figure 22).
6. Concrete temperature at various time intervals after placement.

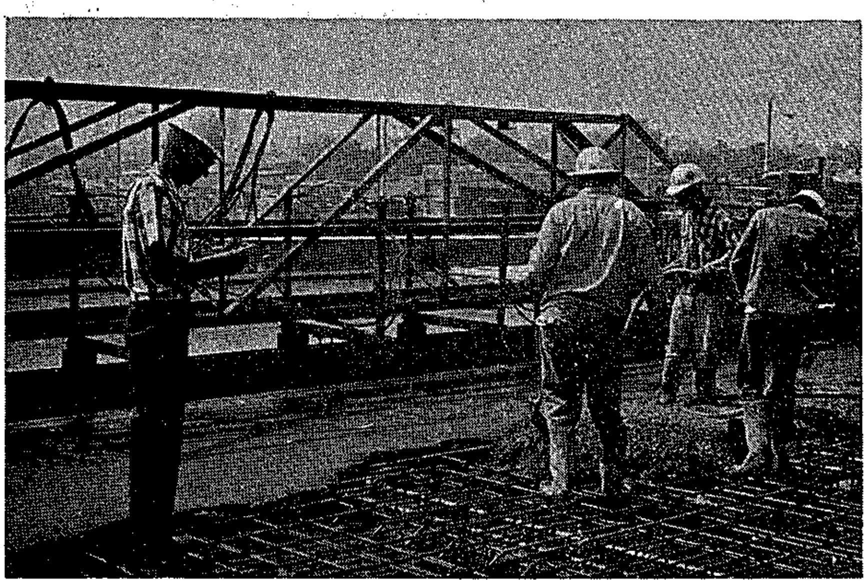


Fig. 19.

Recording concrete placement

Fig. 20.

Excessive bleed water

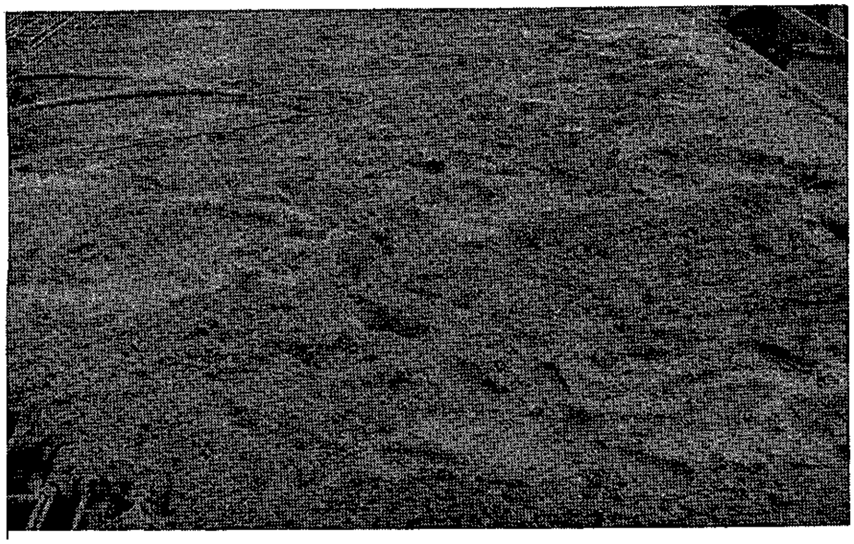


Fig. 21.

Excessive walking in the fresh concrete

Fig. 22.

Recording climatological data

Time placement plots of each operation furnished a visible history of the respective placement (Figure 23).

To reference events during construction with final results, the decks were laid out in a grid pattern at 10-foot intervals along girder lines. For easy reference, the majority of data was recorded on duplicate grid sheets (Appendix A).

EVALUATION

The variables incorporated into this study are to be evaluated by comparing the collected construction data with properties of the finished deck. These properties will include cracking and other defects, and abrasion and skid resistance.

A number of cores will be taken both before and after traffic is allowed on the decks. Of primary interest are those taken through the same cracked areas at different times. These cores will be examined visually and microscopically in the anticipation that some measure of progression can be determined of both the macrocracks and the microcracks. In addition, some cores will be tested for abrasion resistance to see if any correlation can be found between this property and deck durability.

The most practical way to compare the influence of controlled study variables on deck durability appears to be in reducing the various durability parameters - cracking, abrasion resistance, etc. - into a single quantitative value.

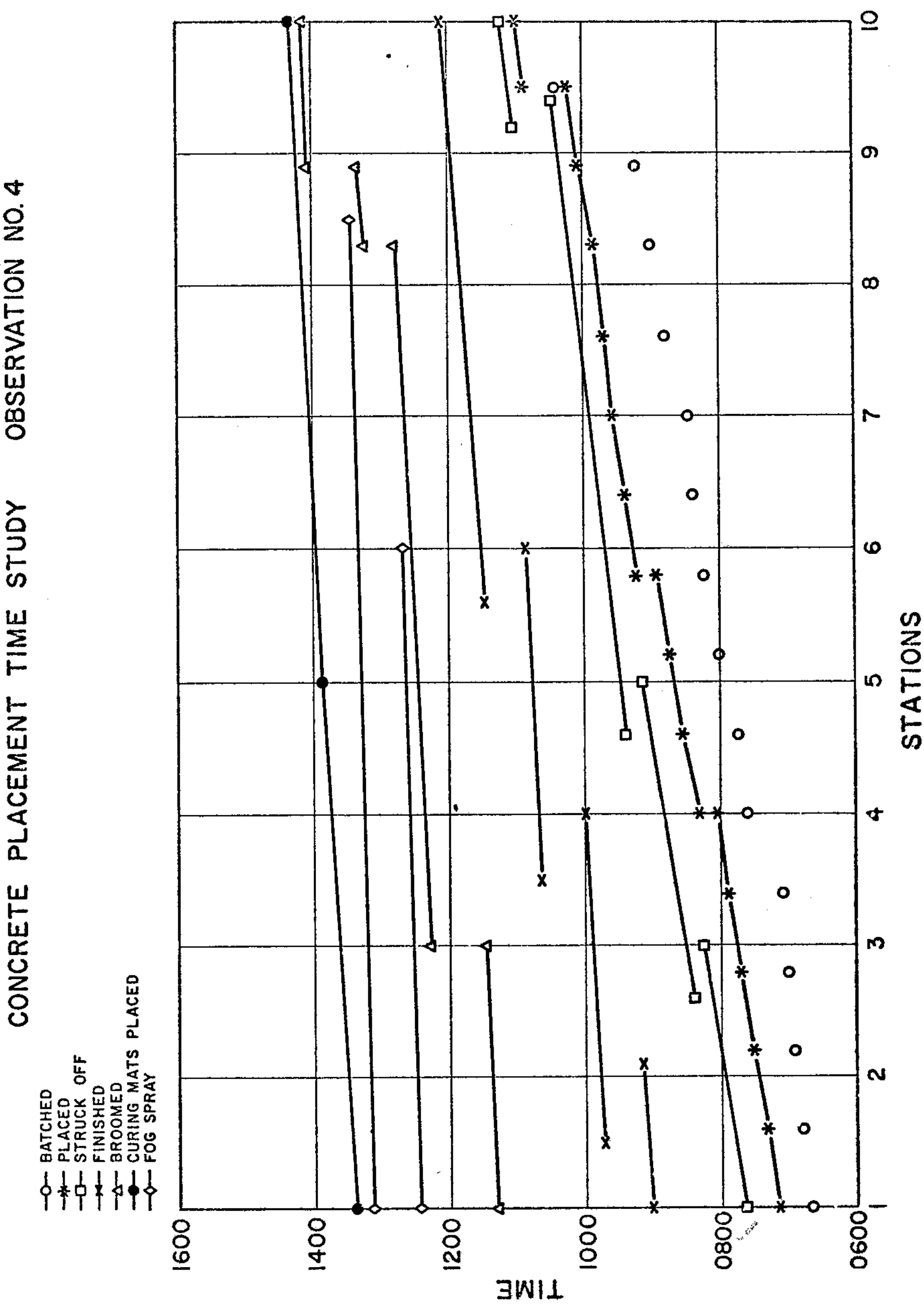


Fig. 23 Time Placement Plots

Before the single value can be obtained, however, each of the parameters must be evaluated quantitatively. Developing a system whereby this can be done is one objective of this study. So far, all efforts in this direction have been concentrated on a deck cracking rating system, and one has been developed which appears to be a useful tool in comparing over-all cracking severity in concrete decks.

CRACK RATING

Rating the crack severity of concrete decks is highly subjective. There is not always agreement on which should be given the greatest weight, with respect to detrimental effect on a deck, crack size or total number. Generally, crack size is considered to be more harmful, and the rating system developed reflects this. However, a large number of small cracks could eventually cause deterioration, hence the system promotes the assigned weight of this condition.

Observations are referenced to a grid system; the girder lines and 10' longitudinal stations for instance. The cracks are then located, marked and sized, and the information recorded on a grid sheet. (Figure 24).

In making the rating from the plotted information, the cracks are grouped, or counted, according to their width: less than 0.005 inches, greater than 0.005 but less than 0.02 inches, and greater than 0.02 inches. The groups are then treated as follows:

Less Than 0.005 Inches

1. Classify each grid according to the number of less than 0.005 inch cracks that appear in it: "0" for 0 to 3 cracks, "1" for 4 to 10 cracks and "2" for 11 or more.

2. Multiply each classification number by the number of grids in which it appears.

3. Divide the sum of the products in Step 2 by the total number of grids. This is the small crack numerical rating.

Greater Than 0.005 Inches, but Less Than 0.02 Inches

The middle size cracks are rated by dividing the total number appearing in all of the grids by the total number of grids.

Greater Than 0.02 Inches

Before rating the larger cracks, their weight is promoted by multiplying the total number appearing in all the grids by 1.5. They are then rated by dividing this product by the total number of grids.

The sum of the three ratings gives a crack severity rating for the deck. A sample is shown in Figure 25.

Concrete construction practices at the beginning and ending areas of deck placements generally differ from the central area, both in placing and finishing. Furthermore, the underlying support (usually rigid end diaphragms) is different. These local factors appear to create different cracking patterns at the bridge ends than those manifested in the central deck area. Therefore, end areas are excluded in the rating determination.

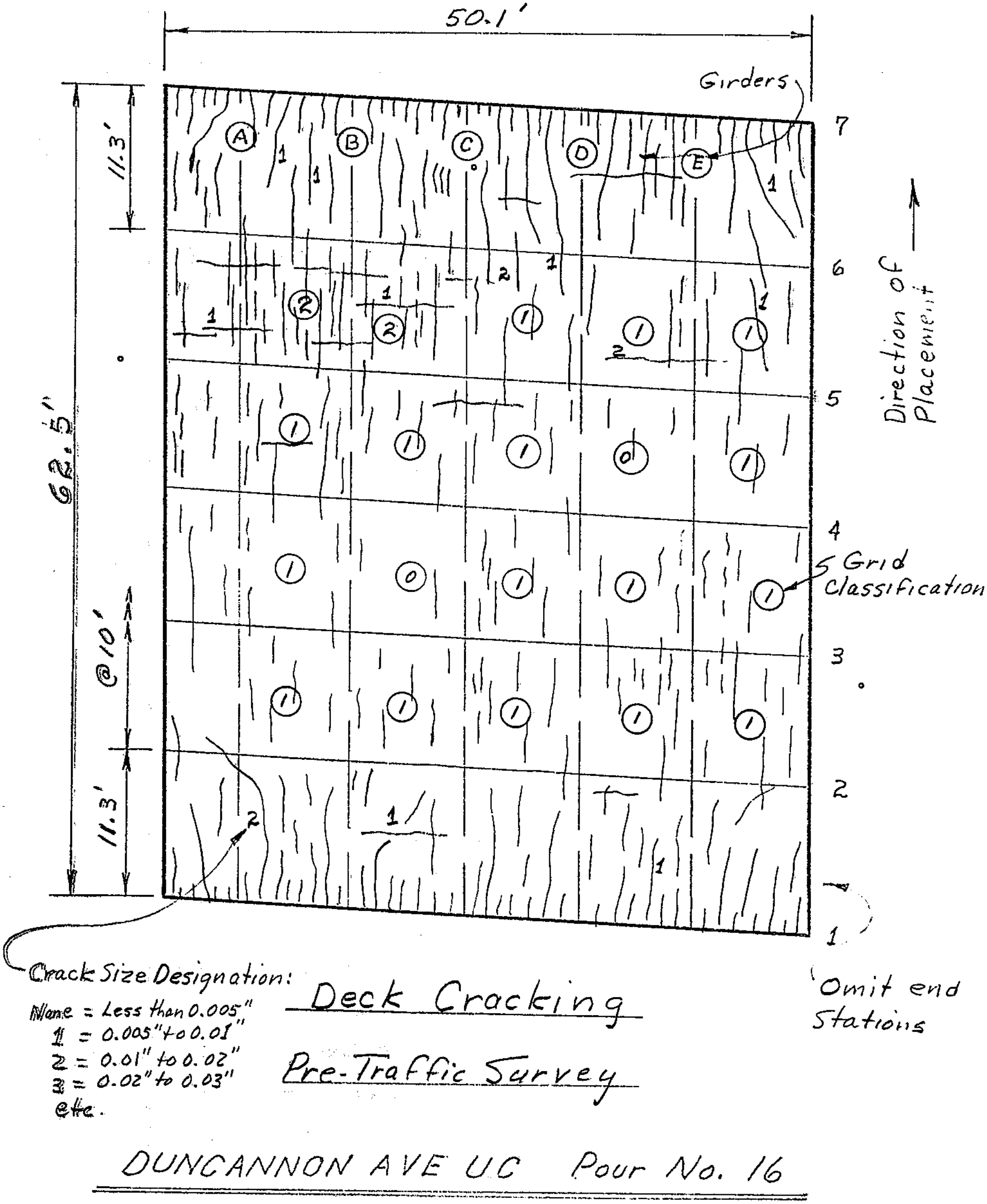


Fig. 25 Crack Severity Rating

DECK CRACK SEVERITY RATING

Observation No. 16

Cracks Less Than 0.005"

Classification	No. of Grids Appearing	Classification Times Number of Grids
0	2	0
1	16	16
2	2	4
	Sum	20

$$\frac{\text{Sum}}{\text{Total Grids}} = \frac{20}{20} = 1.0$$

Cracks Less Than 0.02", but Greater Than 0.005"

$$\frac{\text{Sum}}{\text{Total Grids}} = \frac{4}{20} = 0.2$$

Cracks Greater Than 0.02"

$$\frac{\text{Sum}(1.5)}{\text{Total Grids}} = \frac{2(1.5)}{20} = 0.2$$

Crack Severity Rating: 1.4

Fig. 25

CRACK SURVEY

Two crack surveys have been made: initial and pre-traffic. Age of the concrete varied from 21 to 202 days for the initial and from 295 to 492 for the pre-traffic. For each survey, the deck was thoroughly washed, (Figure 26), and a 4-man team systematically examined the deck for cracks. As cracks were found, a keel mark was placed alongside them. The larger ones were measured and coded according to their width. The location and width of each was later indicated on the respective grid sheet.

Fig. 26.

Conducting a deck crack survey

DEFERMENT

From the wealth of data collected during this study, there is ample reason to believe that considerable knowledge will be gained regarding the effect of certain construction practices on concrete deck durability. However, the only yard sticks available for comparing the practices at this time are the pre-traffic crack surveys. These surveys show concrete age to have a significant effect on deck cracking for several months after construction. As shown in Figures 27 and 28, the older pre-traffic cracking generally increased substantially above the initial cracking level. (The greatest change occurred in the number of cracks and the widening of smaller cracks; the width of larger cracks changed little). The surveys also show the pre-traffic cracking pattern to be unlike that found on structures after they have been under traffic a few years. (The pre-traffic cracking has a longitudinal orientation; whereas, post-traffic cracking usually has a transverse orientation.)

Since the cracking pattern and cracking intensity is expected to be markedly different after traffic uses the decks, it appears that conclusions based on the pre-traffic surveys would be premature. Consequently, conclusions will be deferred until after the post-traffic crack survey.

RESEARCH PROBLEMS

In lieu of conclusions, this report will discuss some of the problems encountered during the project. These problems may be of interest to those concerned with bridge deck construction, particularly to those contemplating a similar research project.

COMPARISON OF INITIAL AND PRE-TRAFFIC CRACK SURVEYS

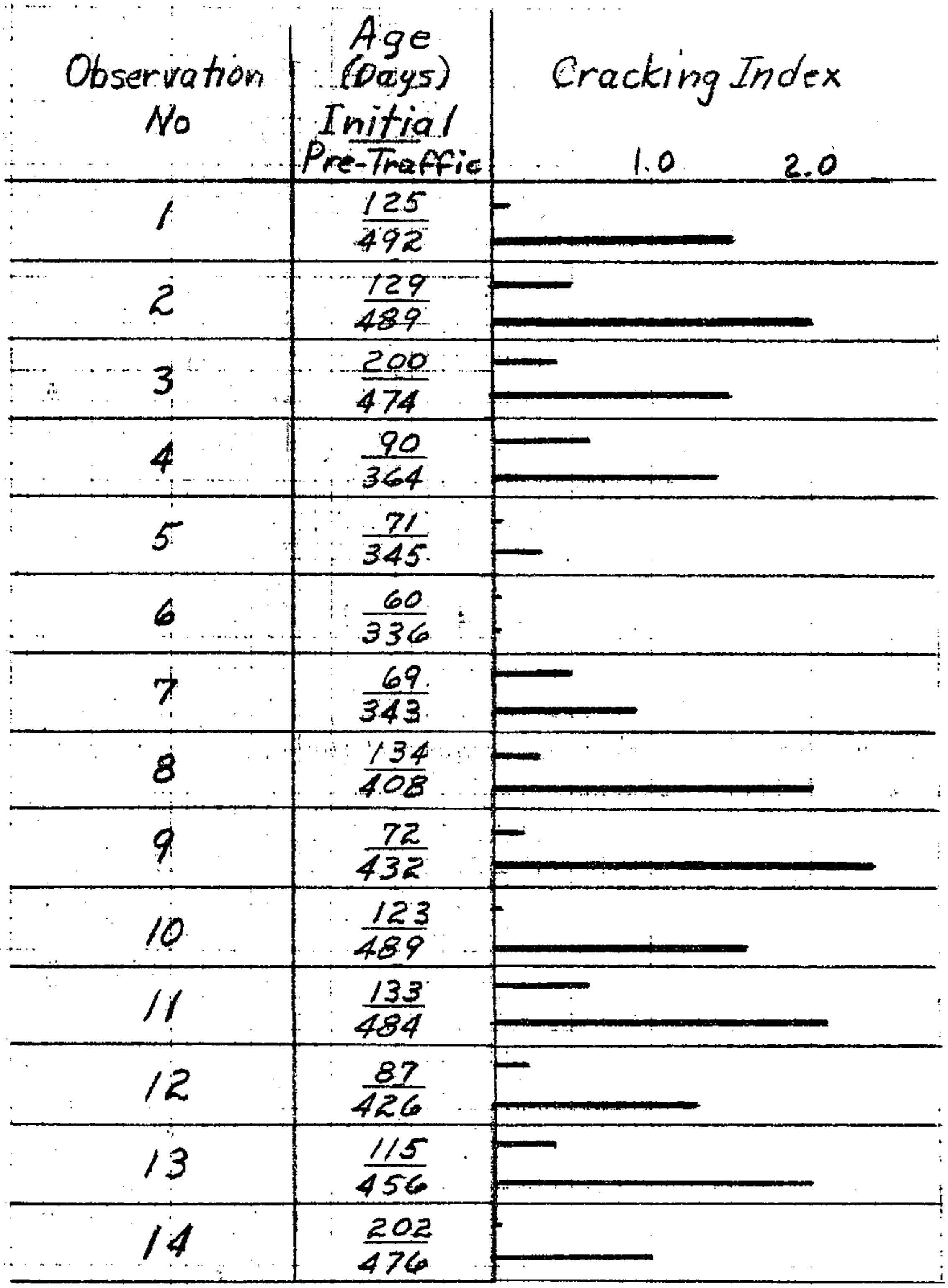


Fig. 27

COMPARISON OF INITIAL AND PRE-TRAFFIC CRACK SURVEYS

Obervation No	Concrete Age (Days) Initial / Pre-Traffic
15	74 / 434
16	67 / 387
17	132 / 406
18	114 / 390
19	58 / 334
20	21 / 295
21	27 / 301
22	89 / 424
23	23 / 297
24	29 / 303
25	73 / 385
26	92 / 366
27	116 / 392

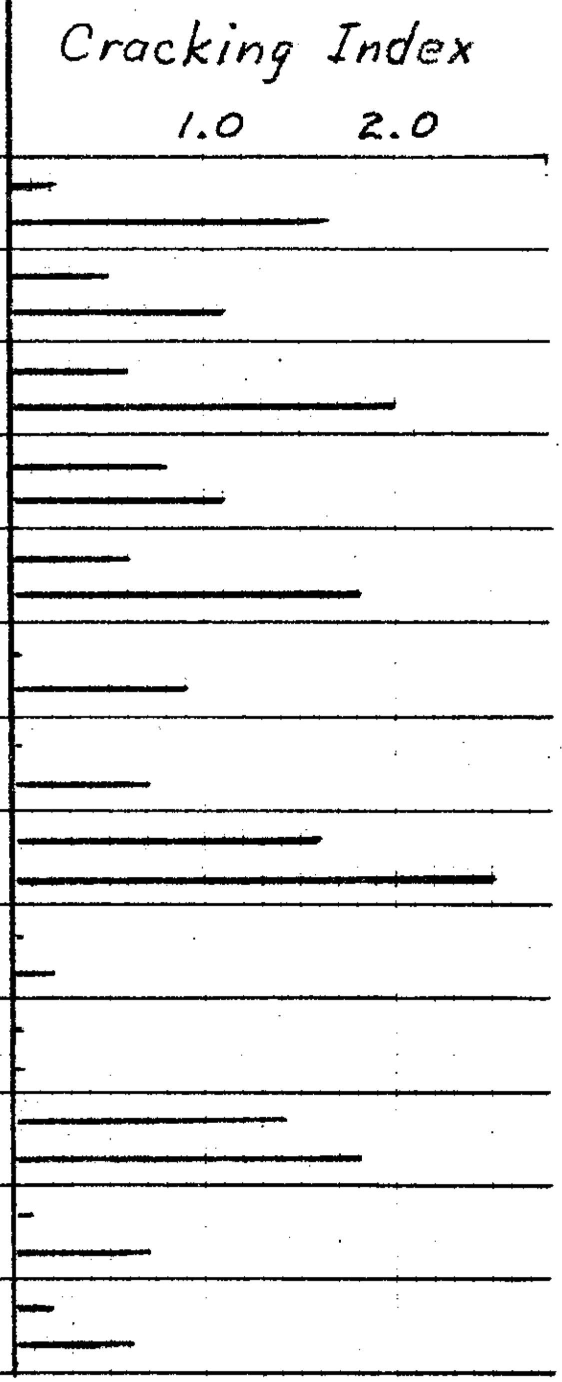


Fig. 28

From the beginning of the project, it was considered important that an accurate accounting be maintained on the amount of water in each batch of concrete. Unfortunately, the accuracy of some of the data accumulated on this matter is not as good as was desired. It is true that the water introduced at the plant or added at the site was metered, and the indicated amounts are probably reliable. But, water used to wash the mixing drum after discharging concrete was not entirely removed prior to charging the subsequent batch, and the amount present could only be roughly estimated. Also, variations in moisture content of the sand probably were not always accurately measured by the moisture meter. Another source of error was the practice of hosing off all cement dust and sand from the trucks after charging. The water entering the drums from this practice had to be estimated. Thus, the data accumulated to show total water and water-cement ratio in each batch of concrete has some margin of error due to the manner in which it had to be taken.

Another area where close observation of water is needed during a deck research project is in curing. It is well known that improperly cured concrete leads to cracking. Consequently, if uniformity in the curing is not maintained during a research project with an objective of determining effect of other variables on cracking, the results could be greatly altered by the curing variable and thereby defeat the objective. Control of curing was delegated to regular construction personnel. It was found that at times the curing did not receive the attention it deserved for research purposes. In future studies, an inspection form will be provided that is to be filled in periodically. The purpose of the form will be to act as a reminder to the inspector, draw attention to the importance of curing uniformity, and provide a record of curing irregularities that might occur.

Visual evaluation of the properties and behaviour of the fresh concrete did not always agree with the consistency as determined by Kelly Ball "slump". Certain batches of concrete appeared extremely fluid when discharged from the placing bucket onto the deck forms. Other batches exhibited a large amount of free water at the front of the placing and finishing operation. In spite of this, the slump recorded for these batches is about 4 inches. No explanation for this anomaly is apparent; however, it is believed that variation in aggregate gradation or caliber of slump measurements could be factors.

The biggest problem during this construction phase was controlling, or scheduling, the planned variables and avoiding unplanned variables. Planned variables were often disrupted by either equipment breakdown, uncooperative weather-- remaining mild when variables to combat hot or windy conditions were being used-- unavailable machinery, or insufficient finishing personnel. In most cases, it was possible to work around the disruptions by changing a variable during placement, or by reclassifying the variable after studying the placement data. There was one occasion, however, when it was impossible to do either and the placement was declared unsuitable for any of the variable classifications. Unfortunately, most of the events that disrupted the scheduling were common problems to construction and as such were unavoidable. Scheduling several repetitions of single variable groups will lessen this problem.

An anticipated problem is how to isolate the numerous variables introduced. The variables are grouped into so many combinations that isolation will be very difficult. For some, about all that can be expected is an indication of their effect on deck durability. In retrospect, the number of variables should have been decreased and the number of placements of selected combinations increased.

The problems encountered will no doubt reduce the over-all effectiveness of the study. Nevertheless, as previously stated, considerable knowledge is expected to be gained, not only on the studies' objectives, but also in more clearly defined directions for further research.

Following is a summary of findings from this phase of the project:

SUMMARY

1. Execution of planned variables that relate to weather conditions or coordinating variable timing with contractor's operations are difficult problems.

2. Numerous repetitions are needed of each planned variable combination to minimize conflict with weather and normal construction variables.

3. Accurate accounting of total water in a transit mix delivery is very difficult, but essential to a research project.

4. Concrete age is a significant factor in the cracking pattern during the first months after placement.

ACKNOWLEDGEMENTS

It took many people to plan and execute the construction phase of this research project. Each served a vital part and deserves recognition. However, it is not practical to list all those who took part. The authors, therefore, wish to thank as a group all who contributed to the project, and give special recognition to a few: W. Ames, J. Woodstrom, and C. Sundquist of the Materials and Research Department; A. Rossing, the Bridge Resident Engineer, and his assistant H. Wolfe; and W. Egloff, of the Special Studies Section of the Bridge Department.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

Appendix A

FACTORS AFFECTING THE
DURABILITY OF CONCRETE BRIDGE DECKS
Construction Observations

PROJECT INFORMATION

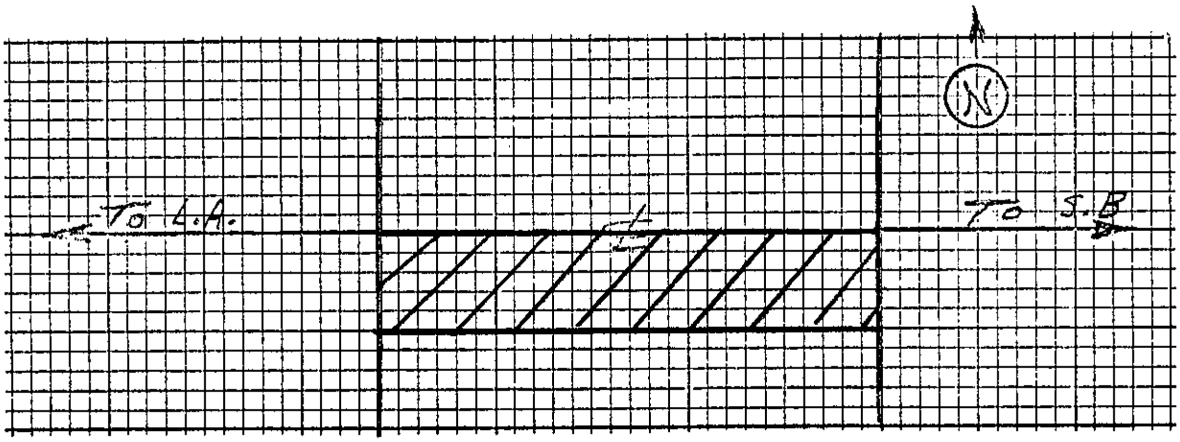
Construction Variable: Late Finish

Date of Placement: 2-2-66 Bridge No.: 53-1824

Contract No.: 14-042134 Bridge Name: Highland Ave. OC

Road: 07-LA-210 - R33.7/R35.9 Bridge Type: Box Girder ~ S.S.

Limits: Magnolia Ave. to Highland Ave. Section Placed: First ½ of S. Half



Contractor: Peter Kiewit

Contractor (Structures): Same

Resident Engineer: Al Rossing

Bridge Dept. Repr.: Same

Bridge Inspector: H. Wolf & F. Bartley

Research Investigators: W. Egloff, B. Neal, C Sundquest

Comments:

14030 - 951128
19503 - 762500 - 35145

Observation No. Sample

MATERIALS

Concrete Supplier Consolidated Rock ~ Irwindale

Aggregate Source San Gabriel Wash ~ Irwindale

Cement (Brand, Source and Type) SW Portland Cement ~ Majave ~ Type II

Mixing Water (Source) City of Irwindale

Admixture None

Type of Mixing (Plant and Truck) 2 1/6 Yd Batch Plant - 3 batches per transit mix truck

Mix Design

	Wts.		Sp.Gr.	Abs.	SE/CV	LART 500 rev.	NaSO4	Mortar Strength
Sand	1312	(SSD)	262	1.2	82	-	1.0	1.25
3/4x#4	970	(SSD)	265	1.2	188	29%	1.0	-
$1\frac{1}{2}$ x#4	1050	(SSD)	266	1.0	186	31%	1.0	-

Cement 564

Water 282

Admixture None

Notes:

FALSEWORK AND FORMS DESCRIPTION

(Pictures/sketches) Generally there is a 1/8" gap between the lost deck forms and girder stems. Lost deck forms appear to be solid enough.

Date falsework removed 2-23-66.

REINFORCING STEEL

(Ties, supports, etc.) Top mat tied every other lap. Is supported by plastic chairs setting on concrete blocks which are spaced @ 5'± C-C longitudinally between girders. 1 3/4" Cover. Bottom mat tied every 1 in 5 laps. Is supported by plastic chairs spaced at 12"± along & between girders.

Observation No. Sample

SUMMARY SHEET

Concrete Delivery Data
and Test Results

Length of Haul 6.2 Miles, 15-20 Minutes

Type of Haul Roads AC & PCC Pavement

(Batch Data (Obtain all pertinent batch data from Resident Engineer)

Load No.	Ticket Number	Truck Number	Depart. Time	Arrival Time	Begin Disch.	End Disch.	No. of Revs.	W/C* (#/C.Y.)	Slump Inches	Temp. Degrees	Unit Weight	Air Content	Cement Factor
1	996-38	4501	0646	0708	0717	0728	177	286					
2	39	4518	0651	0710	0732	0742	200	283	3-4-3½	64°	153.2		6.10
3	40	4506	0702	0728	0745	0800	250	302					
4	41	4509	0715	0734	0800	0812	195	283					
5	42	08	0725		0816	0825	-	312					
6	43	01	0758		0847	0854	-	302	4-5-4½	63°	151.9		6.02
7	44	18	0802		0856	0904	-	295					
8	45	06	0813		0909	0916	-	287					
9	46	08	0830		0917	0927	-	292					
10	47	01	0848		0937	0945	-	283					
11	48	06	0908		1002	1009	-	283					
12	49	05	0938	0958	1010	1018	-	283	3-2½-3½	67°	152.6		6.07
13	50	04	0950	1008	1019	1025	-	277					
14													
15													
16													
17													
18													
19													
20													

*Obtain all necessary data to determine W/C per batch.
Obtain 9 cylinders on 2nd load, 3 for 7, 14, and 28-day strengths.
Obtain 3 cylinders near center of pour and near end of pour for 28-day strengths.

Observation No. Sample

METHODS AND EQUIPMENT

Placement Crane & Bucket

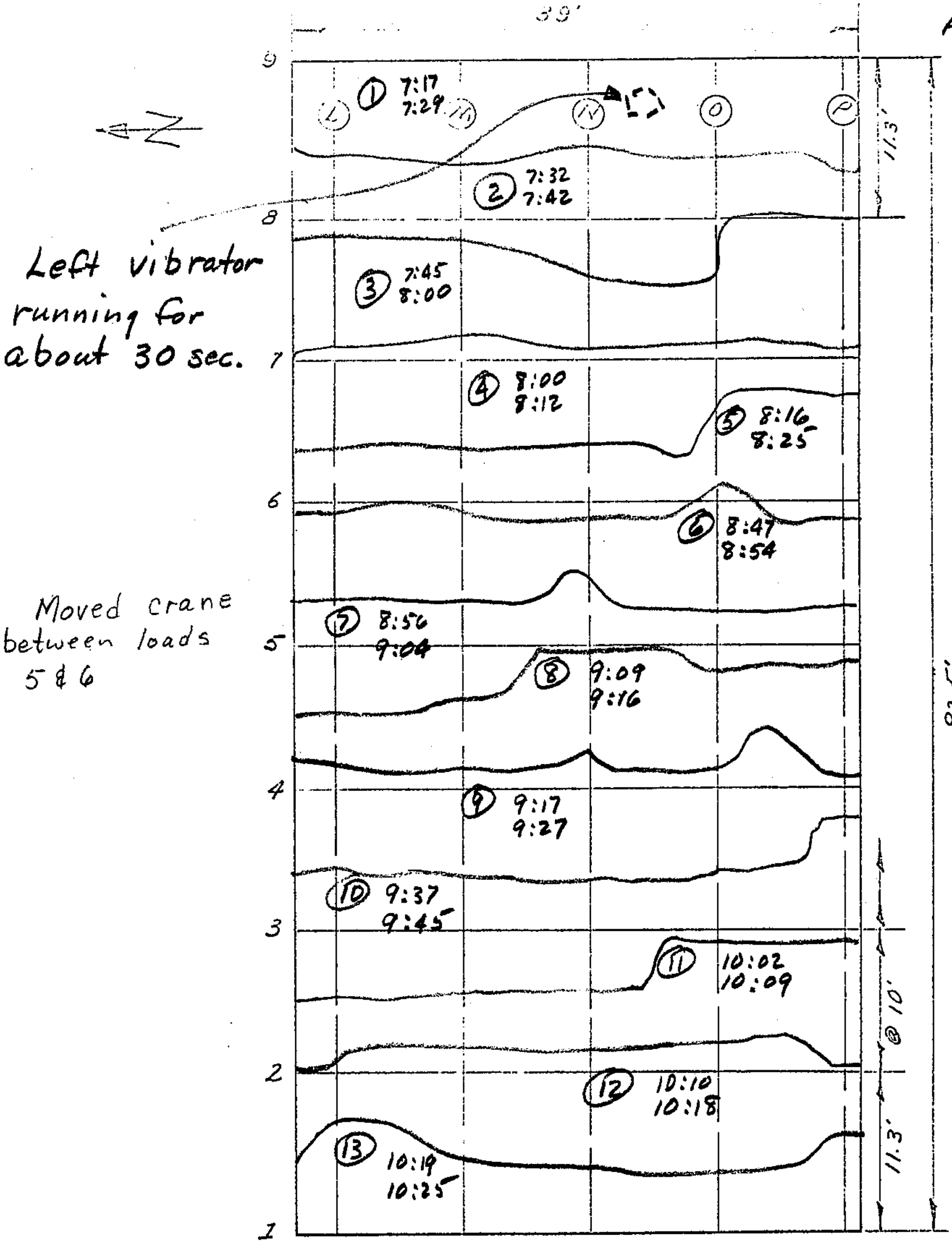
Vibration 2 1/2" McGinnis ~ 10,000 cycles/min

Strike-off Bidwell

Finishing 16' Longitudinal Wooden Plow Handle Float

Curing Wet Rugs

Observation No. Sample



Placing

Scale 1"=10

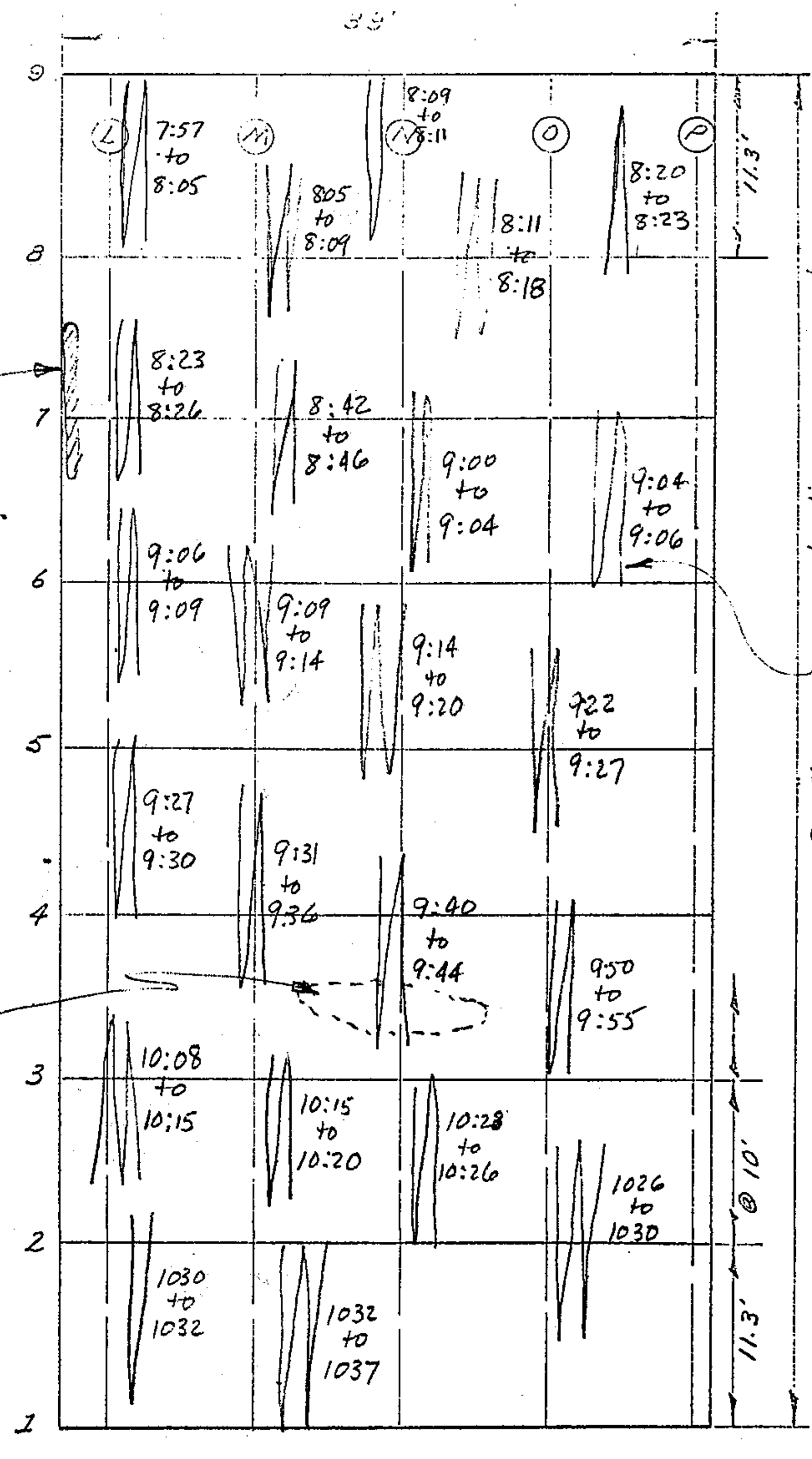
HIGHLAND AVE U.C. Pour No. Sample

Strike-off float left oscillating in this area for over 60sec.

Lot of soupy grout struck off between stations 8-5.

Excessive foot prints in the mud. (Minor repair to Bidwell.)

First & last 3' struck-off with 2x4



Each line represents 1 transverse pass by the strike-off machine.

Strike-Off

Bidwell

Scale 1"=10'

HIGHLAND AVE U.C. Pour No. Sample

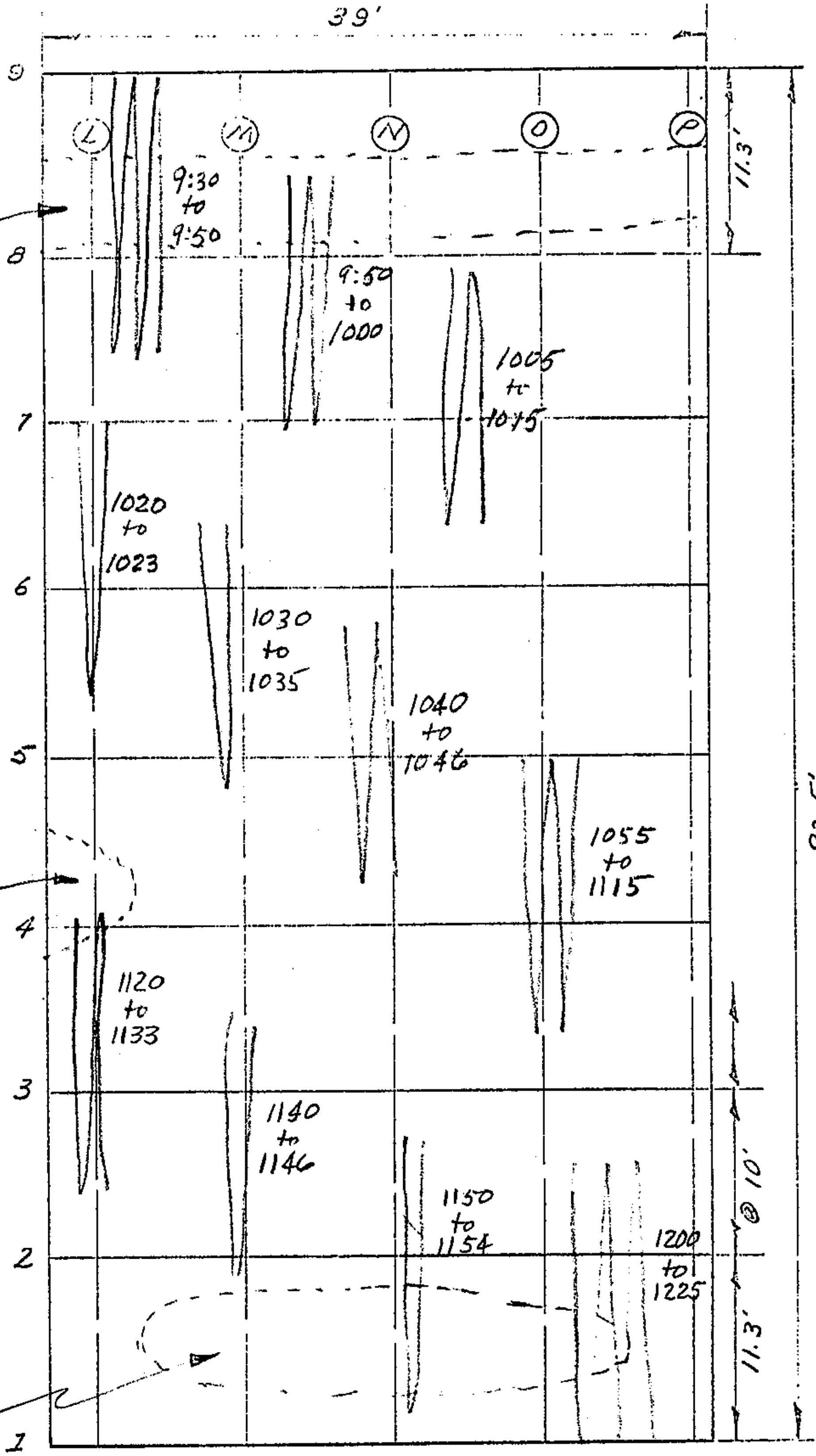
A-7

Low area. Mud brought back from advanced pour

Very little loss of grout

Low spot. Filled from Stock pile

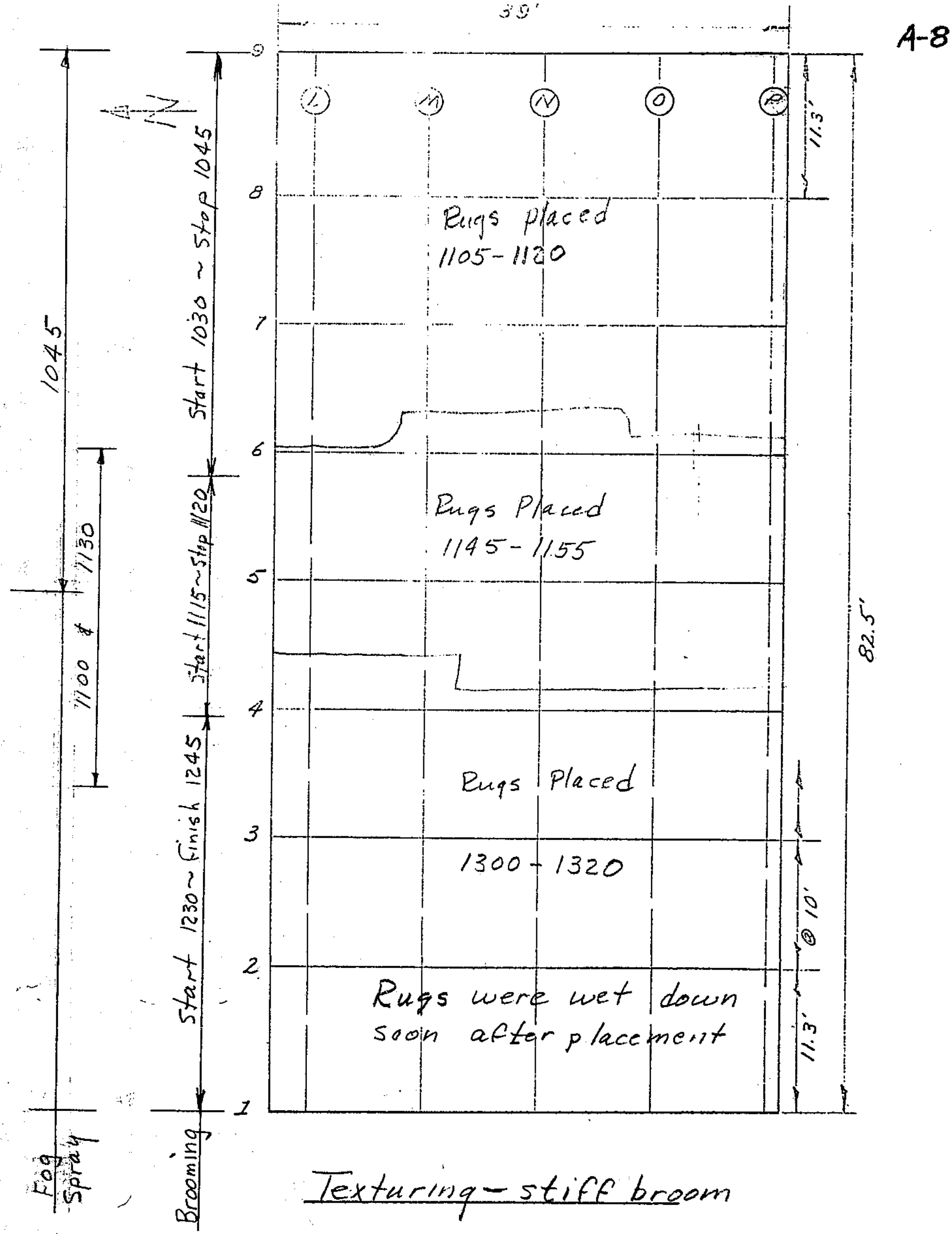
Low spot. Extra mud shoveled in from stock pile



Finishing (Late)

16' Longitudinal-Wooden Scale 1"=10'

HIGHLAND AVE U.C. Pour No. Sample



Texturing - stiff broom

Curing - wet rugs

Scale 1"=10'

HIGHLAND AVE U.C. Pour No. Sample